Energy Research and Development Division

FINAL PROJECT REPORT

Scalable Near Zero Energy Retrofits in Low-Income Multifamily Housing

California Energy Commission

Gavin Newsom, Governor

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PREFACE

The California Energy Commission's Energy Research and Development Division manages the Natural Gas Research and Development program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution, and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with research, development, and demonstration entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater natural gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency.
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity.
- Energy-Related Environmental Research
- Natural Gas-Related Transportation.

Scalable Near Zero Energy Retrofits in Low-Income Multifamily Housing is the final report for the Natural Gas/Buildings End-Use Efficiency project (contract PIR-12-025 and PON-12-503-23) conducted by the Electric Power Research Institute. The information from this project contributes to the Energy Research and Development Division's Natural Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

About 3.3 million low-income households currently rent housing in California, with about 1.7 million low-income renter households spending more than 16 percent of their income on energy. Energy-oriented retrofits can help reduce those costs. The Electric Power Research Institute, BIRAenergy, and LINC Housing retrofitted 32 apartments at The Villages at Beechwood in Lancaster, California with energy efficiency measures to reduce natural gas and electric use by building occupants and the owner. The project team studied the technical and economic scalability of various measures, identified barriers and solutions to implementation in the larger low-income multifamily sector, and increased understanding of hidden market barriers such as asbestos mitigation and incentive program design. Measures that were installed included light emitting diode indoor and outdoor lighting, weather-stripping, smart thermostats, duct and building envelope improvements, efficient appliances, solar thermal water heating, and solar photovoltaic systems. In common areas, contractors sprayed roof foam insulation and tested emerging technologies like aerosol envelope sealing and advanced economizers for the heating and cooling system.

Based on calibrated simulation, the project reduced overall natural gas energy use in 2016 by about a third and electric energy use by more than a quarter. Annually, solar photovoltaic generation offset more than 85 percent of the electricity used in the 32 apartments. In addition to energy savings, tenants reported noticeable improvements to indoor environmental quality. The study results suggest that incentive programs need improvements to encourage property owners to invest in deep energy retrofits. The study also identified common issues that can cause problems for retrofits and strategies to avoid or mitigate those issues. Finally, the study suggests that energy efficiency providers should adopt financial models and practices similar to what has succeeded in the solar energy industry to increase implementation in this sector in the future.

Keywords: Low income, multifamily, whole building retrofit, retrofit, insulation, spray foam, aerosol sealing, economizer, smart thermostats

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EXECUTIVE SUMMARY

Introduction

Energy efficiency and renewable energy are critical elements of California's energy policy. Reducing overall energy use, using energy more efficiently, and promoting non-fossil sources of energy are key components of the state's efforts to reduce the effects of climate change. These strategies also provide other benefits to Californians like reduced energy costs and healthier and more comfortable homes and workplaces.

California goals for promoting energy efficiency have a particular focus on improving the efficiency of existing buildings, many of which were built prior to the state's building energy efficiency standards. An important element of programs that provide energy efficiency retrofits in existing buildings is ensuring that all Californians, including those living in low-income communities, realize the benefits of those improvements. Studies show that low-income these communities, particularly renters, face major barriers to participating in efficiency retrofit programs. California has therefore made it a priority to ensure that those in the most vulnerable communities enjoy equal access to the benefits of the state's clean energy transformation.

According to a February 2016 report from the California Legislative Analyst's Office, 3.3 million low-income households rent housing in California, nearly half of whom report spending more than half their income on rent. Low-income households also spend a larger percentage of their income on energy costs. A United States Department of Health and Human Services study reported that low-income households nationwide can spend more than 16 percent of their income on energy, compared to just over 7 percent for the average household.

Property owners are often unwilling to invest in energy efficiency and renewable energy improvements to their buildings because they do not see the direct benefits from the resulting lower energy use and costs. Multi-family property owners also face rent caps, tenants with difficulties paying rent, high turnover, and high vacancy rates, making it difficult for owners to justify the additional costs of energy efficiency investments, even though high energy bills aggravate the difficulties faced by tenants.

The Scalable Near Zero Energy Retrofits in Low-Income Multifamily Housing project evaluated technical and financial models for retrofits to reduce energy use to near zero in existing low-income multifamily housing. The project was implemented at The Villages at Beechwood in Lancaster, CA, a 28 building, 100-unit, low-income multifamily residence, owned by LINC Housing, LLC, a California non-profit corporation. The project retrofitted 32 apartments and compared the results with data from 30 non-retrofitted apartments used to provide a baseline for comparison. The property was chosen in part because it is located in a climate zone that requires substantial energy for both heating and cooling. The property is also representative of a large portion of the low-income market. Apartments are individually metered and billed for electricity use, but the entire facility is master-metered for gas, with the property-owner billed for all gas use.

Project Purpose

The overarching purpose of this project was to demonstrate the steps and components in the process of implementing very efficient retrofits and to help make related business decisions easy and straightforward for owners.

The project had three major specific goals:

- Develop deep energy-efficiency retrofits, and integrate emerging technologies, solar electric, and solar thermal systems in a practical retrofit package that would be as close to zero net energy as feasible, and also to improve indoor comfort and health conditions.
- Implement the retrofit as successfully as possible and evaluate its success.
- Evaluate and suggest improvements to existing financial models and associated tools to enable scaling of these retrofits across LINC's housing portfolio, as well as California's low-income multifamily market.

Project Process

The project began with site visits to survey the project, inspect equipment, and perform duct and building envelope leakage tests. Based on the survey, the research team developed a baseline simulation model of the complex and developed a list of measures for a very efficient retrofit package.

To select the most effective measures, the team ran simulations with each measure added in isolation to the baseline building and ranked the measures in order of energy impact. The team then simulated the building with all of the most effective measures added. Finally, the researchers simulated the building with each of the measures removed, one by one. Based on the results of the various simulations, the team chose the most cost-effective and practical measures for the retrofit package.

After estimating a simple payback based on installation bids, the team installed the retrofit package in two apartments as a pilot. After evaluating the pilot, proposing a retrofit package to LINC housing management, and receiving a decision, the team designed and installed a data acquisition system, gathered historical energy usage data, installed and commissioned the retrofit packages, collected data from retrofit and baseline apartments, analyzed the results, and prepared their reports. The entire project cost was about $927,000.

The team selected five different multi-apartment buildings encompassing the building types on site for simulation and analysis. Because this project aimed to improve the quality of life for low-income households, it was important to understand the current state of low-income multifamily housing. It was also important to understand the needs and preferences of both the tenants and the property-owners. Another part of the work involved developing a business model for energy efficiency and solar retrofits. The team had to be attentive to the occupants before, during, and after installing energy efficiency improvements.

Some of the major measures installed include:

- A 70-kilowatt solar electric system installed on existing carport structures, costing about $341,000.
- Three 100-gallon boilers in a central outbuilding initially supplied domestic hot water to the three multiplex buildings, with underground piping recirculating hot water on demand. In the retrofit, the team installed a 12-collector evacuated tube solar thermal water heating system on the roof of a 10-plex building at a cost of about $90,000. This collector fed a new 1,250-gallon thermal storage tank with a single 100-gallon boiler retained as a backup. Replacing the original piping with insulated underground piping improved hot water distribution efficiency at a cost of about $70,000. High-efficiency tankless water heaters replaced 40-gallon storage water tanks in each of the duplexes and in the common building.
- One of the most expensive elements in the project was the requirement to mitigate asbestos during installation of low-leakage ducts. Replacing these ducts accounted for almost $244,000 of the project cost, a cost that was not fully offset by energy savings.
- Additional energy efficiency measures installed in the tenant apartments included:
    - Insulating the attic to effectively bring ducts inside conditioned space.
    - Air-sealing the envelope by hand.
    - Sealing and painting above roof-plane ductwork on rooftop air conditioning units.
    - Spray foam roof insulation in one building.
    - Smart thermostats.
    - Low-flow showerheads.
    - Refrigerators in select apartments (installed through the Energy Savings Assistance program).
- Additional energy efficiency measures installed in the common area included:
    - Aerosol sealing building envelope to reduce air leakage.
    - Smart thermostats and heating, ventilation, and air conditioning fault detection and diagnostics system.
    - Spray-foam roof insulation.
    - Spray-foam seal and insulate rooftop heating, ventilation, and air conditioning unit above-roof-plane ducts.
    - Automated economizer for rooftop heating, ventilation, and air conditioning units.

- Smart plug strips.

The team conducted performance evaluations of the retrofits using two approaches. First, the team compared the same apartments or buildings before and after the retrofit. Second, the team retrofitted a “treatment” apartment and had an identical unretrofitted neighboring “control” apartment, which provided a way to neutralize effects of changing weather during the monitoring periods.

Evaluating the natural gas use of the individual apartments proved to be difficult because hot water usage was not metered at the apartment level. Gas usage for 20 rooftop heating, ventilation, and air conditioning units serving individual apartments was monitored separately, as were 22 additional meters for water heaters, common area space heating, and laundry room dryers.

An Electric Power Research Institute data acquisition system monitored electric power for 40 apartments that used both wired and wireless communication to transmit and warehouse data. Power usage of rooftop HVAC units, various air temperatures, and hot water temperatures and flows were monitored. The team installed a nonintrusive load monitor on Building 1 to disaggregate individual device power usage from a single monitoring point. Smart thermostats also allowed for collection of information like setpoints, and were used by some but not all of the occupants.

Broken wireless data communications became an issue for a number of the technologies employed, especially within individual apartments where data routers were frequently unable to communicate. Unit electric use from revenue meters was downloaded from the utility company when available, but this required individual permission from tenants which became a problem because of frequent tenant turnover.

The team trained occupants in the use of the smart thermostats and other equipment; while many occupants enthusiastically embraced the technologies, frequent tenant turnover tended to disrupt continuity and effectiveness of training.

Project Results

Weather changes complicated before-and-after comparisons of energy use. Not only was the 2015-2016 winter colder than the 2014-2015 winter, but the 2016 summer was also hotter than the 2015 summer. These changes caused overall space heating and cooling-related energy use to actually rise after the retrofit. Comparison with the monitored control group, however, indicated that energy use increased much less in the treatment group than in the control group. On average, natural gas used for space heating was reduced by more than half in the treatment group relative to the control group. Similarly, electric use related to cooling and ventilation was reduced by about an average of about one third in the treatment group relative to the control group. Overall electric use dropped by nearly 40 percent in the retrofit group relative to the control group in 2016.

Calibrated simulations indicate that annual electric savings per apartment were about 560 kilowatt-hours for ductwork and insulation, 150 kilowatt-hours for smart thermostats, and 400 kilowatt-hours for lighting, while 240 kilowatt-hours were added for pumping related to solar water heating. Overall, calibrated simulations indicate the usage of the average multiplex apartment would have been about 5,770 kilowatt-hours in 2016 without the retrofit, while actual usage after retrofit was about 4,215 kilowatt-hours, a 27 percent reduction.

Energy consumed depended heavily on weather and occupant habits. The installed solar electric system generated more than 117,000 kilowatt-hours per year or about 3,650 kilowatt-hours for each of the 32 apartments, providing a value of $600 per apartment. Annually, in 2016 the electricity produced by the photovoltaic system offset more than 85 percent of the electricity used in the retrofit apartments.

Natural gas saving per apartment, according to calibrated simulation, was about 75 therms for ductwork and insulation, 20 therms for smart thermostats, and 60 therms saved for solar water heating plus distribution piping insulation. Efficient lighting added 10 therms to the heating load, because less waste heat was released into the rooms. The average annual gas usage for the entire complex from 2010 until 2013 was 49,037 therms, or about 490 therms on average for each of the 100 apartments. Tabulated gas savings for the 32 apartments retrofitted were 4,653 therms, which amounts to about 30 percent savings overall.

Occupant behavior greatly influenced individual apartment savings. Frequent tenant turnover made it difficult to analyze energy use by apartment. Some occupants left air conditioning running constantly, whereas others were frugal. Some carefully programmed their smart thermostats, while others used them as simple on-off switches. Three types of smart thermostats were used and showed substantial benefits that differed depending on the thermostat. However, the sample size of 10 each of the models were too small to draw definitive inferences as to which model was superior.

The savings from reduced envelope leakage and the community hot water retrofit, including the solar hot water and new storage and distribution components, came at a high cost, especially for the hot water retrofits, and for the duct leakage reduction, which required asbestos remediation. The two pilot retrofits achieves large duct savings, but equivalent savings were not achieved in most of the other apartments, likely due to lower quality work in the follow-on phase of the work. Comfort improvements were also achieved, but not quantified.

Project Benefits

After the very efficient retrofits, the apartments showed an average net reduction through improved efficiency of about 4.3 kilowatt hours each day. Additionally, the photovoltaic array generated about 10 kilowatt-hours per day for each of the 32 apartments. Since California has nearly 7 million apartment residents, assuming the same potential for electric energy savings and generation per apartment, one could project potential net savings statewide of more than 36 gigawatt hours each year.

At the community scale, the retrofits showed about one-third reduction in gas use, or about 4,600 therms annually for the 32 retrofit apartments (145 Therms per apartment). Scaling this to the entire state, there is potential to reduce energy by about 1 billion therms in multifamily properties alone. The projected benefit in greenhouse gas reductions for California is 5.4 million metric tons of carbon dioxide annually from the natural gas savings alone.

This project shows there are also nonenergy benefits resulting from efficiency and renewable energy retrofits to occupants and tenants of low-income communities. Studies have shown nonenergy benefits such as improved health and comfort, increased tenant retention, and improved ability to afford necessities like food, medicine, health care, and rent. In this project, a mother described how better indoor temperature and humidity control through better insulation had helped with her daughter's nosebleeds. Another occupant indicated that his comfort was considerably improved with the installed efficiency measures and smart thermostats.

Future work in affordable and low-income communities must emphasize both energy and nonenergy benefits. Programs need to provide incentives for energy efficiency to tenants and the property owners who must make substantial investments to implement these measures. The research team recommends developing financial models similar to those used in the solar industry for the energy efficiency industry, and that future research aim to fill any gaps in data required by financing institutions. More research is required to find simpler, more practical very efficient retrofits that can be more cost-effective and, if financing problems can be solved, be performed much more broadly.

The research resulted in the following lessons learned and recommendations:

- Many of the financial tools considered, including utility allowances and calculators, were complex, difficult to understand, and hard to access. Additional sub- or intra-county utility allowances, or property-or zip code specific utility allowances, would be more valuable to owners and tenants.
- Finding, evaluating, and negotiating with various financing programs is very time consuming. Using a single point of contact for stacking financing and incentive programs could save time and improve program efficiency.
- Despite educational tools and personal communication to explain to tenants the value of behaviors that reduce energy use, considerable energy savings were taken back (for example, when occupants saw lower utility bills and chose to increase their energy usage).
- Programs run by the State of California, such as Energy Upgrade California, have hidden costs and restrictions that make them challenging to use. Introductory processes should be easier and more transparent.
- Multifamily Affordable Solar Housing program requirements should be relaxed and program eligibility criteria be regularly evaluated and adjusted based on energy savings potential for the low-income multifamily market.
- Environmental remediation efforts such as asbestos removal are expensive and can lead to delays. These efforts are also inconvenient for tenants and often hard-to-schedule, since they require the tenant to vacate the property for extended periods.

- Solving the split incentive issue for low-income multifamily housing will require many experts to work together. This includes developers, tenant advocacy groups, nongovernmental organizations, financing experts, state and federal government agencies, foundations and many others.
- To foster change in the financial support of efficiency upgrades, the efficiency community should adopt the practices of the renewable community, if for no other reason than to be able to secure financing for deep retrofits as easily as one can secure financing for solar photovoltaic systems.
- State and federal policies need to be updated to recognize efficiency as thoroughly reliable. Policies that affect efficiency differently from local energy generation should be updated to view and treat efficiency on an equal footing with generation, especially in the financial community. Doing so will help encourage owners to adopt efficiency as a leading strategy to fight climate change.

CHAPTER 1: Overview

According to a February 2016 California Legislative Analyst's report, about 3.3 million low-income households rent housing in California and about 1.7 million low-income renter households spend more than half of their income on housing (Dyson, Chen, and Samiullah, 2010). In addition, a United States Department of Health and Human Services studied reported that low-income households can spend as much as 16.4 percent of their income on energy, compared to 7.2 percent for the average household (California Department of Community Services and Development, 2017). Low-income families need affordable housing with low rents and energy costs that also provides comfortable, healthy, and durable shelter. On the other hand, multifamily property owners face challenges from rent caps, tenants with difficulties paying rents, and properties with high turnover and moderate to high vacancy rates.

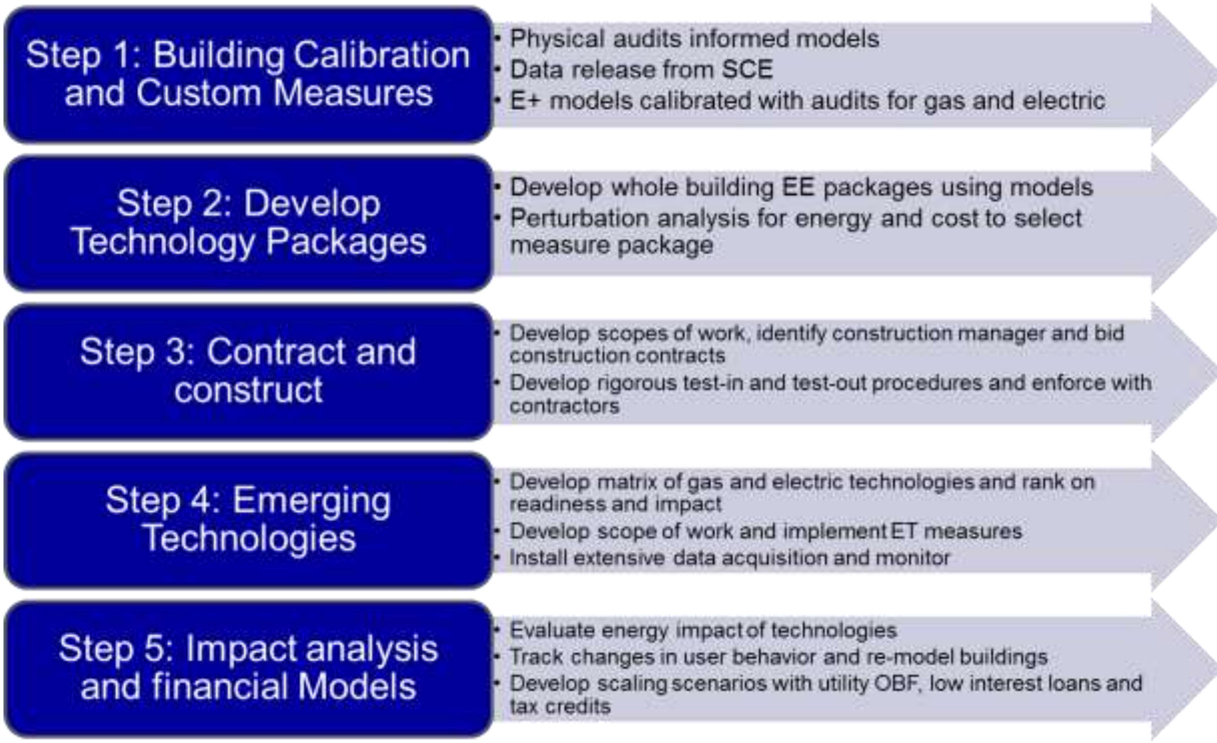
A well-designed program supporting very efficient retrofits (VER) could allow multifamily property owners to raise rents to at least partially offset financing costs for VER, provided the total rent plus utility costs are lowered and the property is modernized. However, the low-income multifamily (LIMF) market lacks the information to even consider VERs, and even if interested, does not readily have the means to design, finance, and implement energy-efficiency retrofits with the possible exception of the most basic improvements. Exacerbating this situation is the large number of multifamily buildings that are not energy efficient. The property retrofitted in this Scalable Near Zero Energy Retrofits in Low-Income Multifamily Housing project is a good example – the apartments use more energy per square foot than a typical home in Sacramento.

There are approximately 2.7 million multifamily units in California that pre-date any energy standards and about 3.7 million multifamily dwellings built prior to any significant impact from the energy standards. This target market is substantial, and the energy savings potential very large as discussed in the cost-effectiveness section later in this document. The LIMF market has a substantial need for best-design, best-practice retrofit information. There also appears to be no practical access to determining the potential energy savings and resulting benefits to the property owners and their tenants, nor the technical and financial information for how to implement a VER even if they chose to do so.

This project helps satisfy the LIMF market demand for energy efficiency and technical and financial information. Packages, practices, and methods produced in this project are applicable to the entire existing multifamily market, making the project more important.

The overarching goal of this project is to demonstrate the steps and components in the process of implementing very efficient retrofits, and to make related business decisions both easy and straightforward for owners. Figure 1 shows the process used to select and evaluate the energy efficiency measures.

Figure 1: Overall Process for Project Execution



Source: Electric Power Research Institute

The project started with selection of the site to be retrofitted. The Villages at Beechwood in Lancaster, CA, is a 28-building, 100-unit, low-income multifamily residence, owned by LINC Housing, LLC, a California non-profit corporation. The project retrofitted 32 apartments within the complex.

Next, the research team performed a thorough audit of the components and construction of current structures to be retrofitted. The audit included identifying energy-consuming items, occupant interviews regarding small electric appliance use, and thermostat settings (both queried and observed). Audit information included envelope components and areas and equipment age and efficiency ratings. This data was then used to develop computer models of the buildings. The team used the models to run simulations and made adjustments to fit the audit data, which produced calibrated models. This information allowed the research team to identify the largest energy uses and how best to address them with efficiency measures. The team then analyzed energy-efficiency measures to determine their impacts on energy use, taking into consideration other factors that might alter their impacts, relative implementation difficulties, availability, and relative scalability. In-depth monitoring of the heating, ventilation, and air conditioning systems was combined with data from smart meters for both electricity and natural gas to verify the performance of the energy efficiency measures. The team then implemented and evaluated two sets of selected measures, one for the common area and one for the tenant apartments.

CHAPTER 2:
Energy Audit and Baseline Model

Site Visits and Survey

The project began with an energy audit, which included site visits and a survey of energy use. The research team visited the Village at Beechwood site to collect the data needed to perform building energy simulations, and studied individual Beechwood apartments, ancillary buildings, and the complex as a whole. During site visits, investigators measured the apartments and buildings (Figure 2) and recorded data on energy-consuming devices and equipment. Tests were performed to measure duct leakage using the Duct Blaster, and to measure building envelope leakage using the Blower Door test. Researchers also physically viewed the apartments, including as many of their construction components as possible, allowing a survey of the appliances in several apartments. After developing computer models, another site visit followed to investigate the duct systems in detail.

Figure 2: View of Village at Beechwood Property with Key Energy Systems Identified

Source: Electric Power Research Institute

Figure 3: Example of Beechwood Community Multifamily Construction

Source: Electric Power Research Institute

The team developed computer-aided energy simulation models to analyze the energy use in the tenant buildings, starting with the development of a library of the different apartment types. Appropriate apartment types were combined to create a model of each building. The team chose to investigate each of the different configurations of bedrooms and construction types. Table 1 lists the variety of building types at the Beechwood campus.

Table 1: Matrix of Dwelling Unit Types and Numbers per Building

No. of Buildings	Bedrooms per Unit	Units per Building
2	1	10
2	2	10
2	2	8
11	2	2
11	3	2

Source: Electric Power Research Institute

The distribution of dwelling units and building types at Beechwood resulted in five different model types representing the actual buildings at Beechwood (Table 2).

Table 2: Matrix of the Units and Buildings at the Village at Beechwood

Beechwood Building #	Bedrooms per Unit	Units per Building	Front Orientation
1	2	8	North
2	2	10	West
3	1	10	East
20	2	2	North
21	3	2	North

Source: Electric Power Research Institute

Initial Site Visit

The team developed each of the computer models based on actual audited buildings. Upon an initial visit by the research team, the basic construction type was noted, the building dimensions measured. The nameplates of the rooftop units, furnace, and water heater for domestic hot water were pictured and recorded. The roof-mounted packaged heating, ventilation and air conditioning (HVAC) units on Building 1 were rated at 12 seasonal energy efficiency ratio (SEER) and 80 percent annual fuel utilization efficiency (Figure 4). The domestic hot water outbuilding housed two gas-fired 0.82 energy factor 100-gallon tanks, which provide hot water to 26 apartments in Buildings 1, 2, and 3.[1] Figure 5 shows two of the three domestic hot water units per outbuilding. Another identical system provided hot water to Buildings 4, 5, and 6. These systems had circulation pumps activated by demand for hot water that would not run if the water at the tap was already hot. Pumps were behind the tanks, and were not visible. The laundry room was well-equipped with 10 washers and 10 dryers and was located in the backside of the common area (Figure 6). The refrigerators were top-freezer style (Figure 7) and the ranges were standard gas-fired (Figure 8). All windows were double-paned with metal frames (Figure 9). Figure 10 shows the ceiling insulation through a damaged exterior wall, which exposes an estimated two inches of fiberglass batt insulation.

Figure 4: Rooftop Packaged Heating, Ventilation, and Air Conditioning Units on Building 1

Source: Electric Power Research Institute

[1] An energy factor is a measure of overall efficiency for a variety of appliances. The higher the factor, the more efficient the appliance (www.energystar.gov).

Figure 5: Domestic Hot Water Tanks

Source: Electric Power Research Institute

Figure 6: Washer and Dryers

Source: Electric Power Research Institute

Figure 7: Top-Freezer Refrigerators

Source: Electric Power Research Institute

Figure 8: Standard Gas Ranges

Source: Electric Power Research Institute

Figure 9: Double-Pane Windows with Metal Frames

Source: Electric Power Research Institute

Figure 10: Damaged Section of Exterior Wall with Two Inches of Batt Insulation

Source: Electric Power Research Institute

To help estimate the miscellaneous electric load (MEL), the team developed a tenant questionnaire regarding the variety and types of electric-powered equipment plugged into wall sockets. The Village at Beechwood staff assisted in developing the questionnaire, and personally interviewed approximately 30 tenants. Table 3 provides the details of the MEL usage by tenants with average MEL per apartment estimated to be 1,273 kilowatt-hours per year (kWh/yr), with a survey sample of n= 25.

Table 3: Miscellaneous Electric Loads Use by Tenants

ELECTRIC USE	AVERAGE QUANTITY	NUMBER OF HOURS (AVG)	Watt Draw	Energy/Unit (kWh/yr)	Source
AIR CLEANER	0.04	2.00	400	65.70	Survey
BABY MONITOR	-	-	200	22.80	Survey
BLENDER	0.40	0.17	800	7.00	Survey
CABLE BOX	0.56	8.94	50	134.10	Survey
CLOCK RADIO	0.08	16.00	12	14.90	Survey
COFFEE MAKER	0.52	0.47	1,250	61.20	Survey
CURLING IRON	0.36	1.00	1,500	1.00	BA MELs
DEEP FRYER	0.08	0.14	600	20.00	BA MELs
DVD PLAYER/VCR	0.72	4.20	120	49.80	BA MELs
ELECTRICAL GRILL/GRIDDLE	0.08	0.14	1,100	180.00	Survey
ELECTRIC SHAVER	0.04	0.08	200	1.00	Survey
FAN (PORTABLE)	0.46	8.00	120	11.30	BA MELs
HAIR DRYER	0.44	0.50	1,850	41.10	BA MELs
HEATING PADS	0.08	0.03	800	3.00	Survey
FISH TANK	0.08	24.00	25	180.00	Survey
MICROWAVE	0.92	0.64	1,100	131.20	Survey
PRINTER	0.12	0.08	100	15.50	Survey
SLOW COOKER/CROCK POT	0.24	3.50	350	16.00	BA MELs
SUBWOOFER	-	1.00	600	68.30	BA MELs
TELEVISION	2.00	6.61	200	125.40	Survey
TOASTER	0.48	0.63	1,000	45.90	BA MELs
TOASTER OVEN	0.12	0.25	1,200	32.30	BA MELs
VIDEO GAMING SYSTEM	0.24	3.50	600	20.40	Survey
WAFFLE IRON	0.08	0.14	850	25.00	BA MELs
Total				1,273	

Source: Electric Power Research Institute

Second Site Visit

The second site visit included a certified third-party inspections firm and conducted blower door, duct blaster, and flow hood HVAC testing procedures (Figure 11). The tests evaluated the improvement of thermal performance of the apartments to identify impacts on energy bills and occupant thermal comfort. The duct Blaster test measured duct leakage by pressurizing ducts to 25 Pascals (Pa) and recording the cubic feet per minute (CFM) needed to achieve a stable 25 Pa with the pressure-fan sealed to the air return and all supply ducts sealed with tape. The blower door tests to measure leakage in the building envelope were conducted with all windows and doors closed except the front door, where the blower door equipment and fan were installed. The CFM needed to pressurize the apartment to 50 Pa was reported. Table 4 summarizes the results of these tests, which were used in development of the baseline simulation models.

Figure 11: Blower Door Test in Progress

Source: Electric Power Research Institute

Table 4: Duct, Envelope and HVAC Performance Test Results before Measures

Units								CFM	CFM			CFM		CFM
Test Pressure (Pa)								25	25	%	%	50		25
BLDG #	UNIT #	Type	UP or Down Stairs	End or Middle Unit	Condi-tioned Floor Area	Air Condi-tioner Size (ton)	Air Condi-tioner Air Flow	Duct Leakage	Duct Leakage To Outside	% Duct Leakage To Outside	Duct % Leakage	Infiltration	ACH_{50}	Air Flow GRID
3	20	1 BR	Up	End (10)	582	3	1092	177	123	31%	16%	1055	13.6	660
5	44	1 BR	Down	Middle (10)	582	3	1092	177	123	31%	16%	1350	17.4	575
1	7	2 BR	Up	Middle (8)	842	3	1092	192	168	13%	18%	1380	12.3	781
4	29	2 BR	Donw	End (10)	842	3	1092	192	168	13%	18%	1570	14.0	654
27	98	3 BR	Up	Duplex	1045	3	1092	279	252	10%	26%	2059	14.8	827
21	85	3 BR	Down	Duplex	1045	3	1092	378	273	28%	35%	1744	12.5	634
					AVERAGE	3	1092	233	185	21%	21%	1526	14.1	689

Source: Electric Power Research Institute

Developing Baseline Energy Models

The research team used the data collected from the survey, site visits, and performance tests to construct energy models of the buildings at Beechwood. Table 5 lists the existing energy features used to develop the base-case energy models for different apartment types. These apartment types were modeled using BEopt v2.0.0.6, a building energy modeling software suite designed and developed by the National Renewable Energy Laboratory for simulating single dwelling units or for developing optimization analyses. BEopt provided a convenient user-shell for EnergyPlus v8.1, one of the most sophisticated energy modeling engines available at that time.

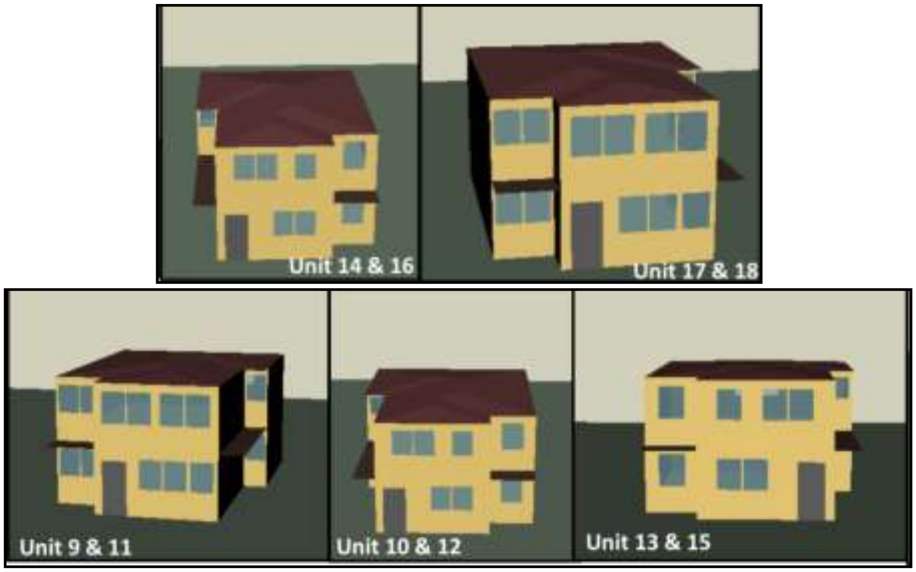
Table 5: Baseline Energy Features for Modeling Beechwood Manor Apartments

Modeling Parameter	Beechwood Base Case Package
Miscellaneous Electric Load	1273 kWh/year per unit
Heating / Cooling Setpoints	74 / 74
Interior Shading Coefficient	0.95
Attic Insulation	R-6.4 cellulose in ceiling (Assembly U-Factor = 0.1220)
Roof Material	Light colored gravel (Absorptivity = 0.75 , Emissivity = 0.91)
Wall Insulation	2" cellulose, 2x4 16" o.c. (Wall Assembly R-Value = 0.1250)
Exterior Finish	Stucco, light color (Absorptivity = 0.55, Emissivity = 0.90)
Window Types	Double pane, metal frame (E Factor = 0.76, SGHC = 0.67)
Window Area, Building 1	Front = 126 sqft, Back = 76 sqft
Window Area, Building 2	Front = 126 sqft, Back = 76 sqft
Window Area, Building 3	Front = 126 sqft, Back = 40 sqft
Window Area, Building 20	Front = 125 sqft, Back = 62 sqft, Right = 4 sqft
Window Area, Building 21	Front = 126 sqft, Back = 84 sqft, Left = 4 sqft, Right = 36 sqft
Air Leakage	14.1 ACH50
Refrigerator	Top-mounted freezer, 480 kWh/year
Dishwasher	318 kWh/year
Clothes Washer	On-Site Laundry Room
Clothes Drier	On-Site Laundry Room
Lighting	100% Incandescent
Air Conditioner	12 SEER / 10.25 EER
Furnace	80% AFUE
Ducts	32% Leakage, Uninsulated
Water Heater	Multiplex: Shared portion of 100gal Boiler (0.80 EF)
	Duplex: 40gal Storage (0.62 EF)
Hot Water Distribution	Copper tubing, trunk-and-branch archetechture, uninsulated

Source: Electric Power Research Institute

BEopt v2.0.0.6 was unable to provide EnergyPLUS with the input values appropriate to buildings with more than five bedrooms. Multiunit buildings with more than two dwelling units were therefore divided into paired up- and down-stacked units for the two end-units and the middle units, with adiabatic surfaces (surfaces through which no energy transfer takes place) where the stacked units are bordered by another stacked pair, for each of the 1-, 2-, and 3-bedroom apartments. Each up-down pair was simulated using BEopt v2.0.0.6 and the results accumulated to produce simulation results for 8- or 10-plex buildings, all from component up-down unit pairs. Figure 12 shows the "built-up" arrangement with the adiabatic surfaces in black.

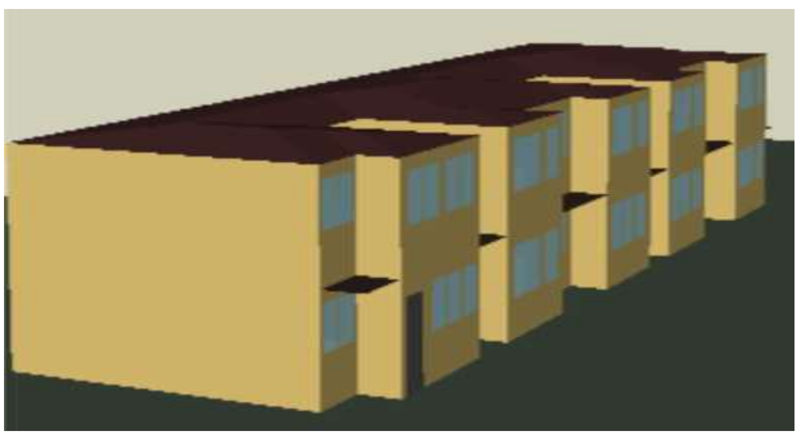
Figure 12: 3D Renderings of Input Geometries Assembled to Form Building 2



Source: Electric Power Research Institute

Figure 13 shows the “built-up” model without adiabatic surfaces in a sample rendering of the various units used in the simulation.

Figure 13: 3D Image of “Built-Up” EnergyPLUS Model Used in Building 2 Simulation



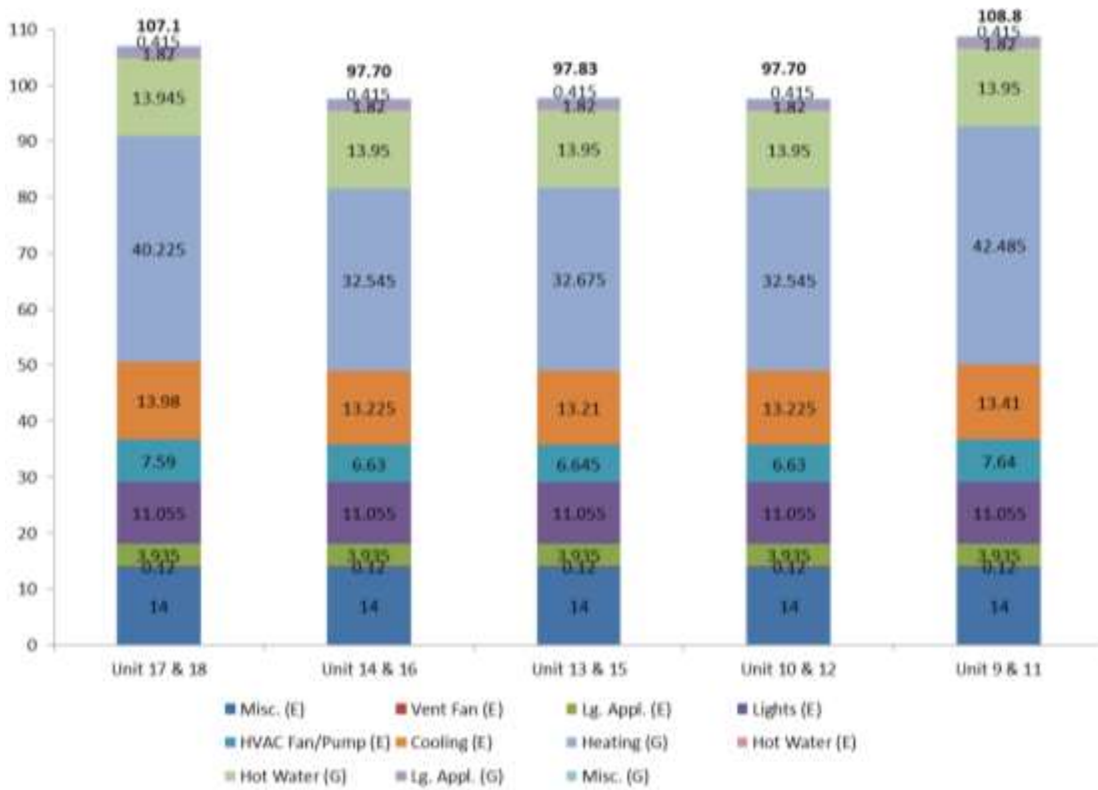
Source: Electric Power Research Institute

At the end of the project, the team was able to simulate the entire building using a later version of the energy modeling software, BeOpt v2.6.0.2, discussed in Chapter 6.

Building 21, a duplex of apartments with 3 bedrooms each, was unique in that each living unit was simulated individually. The input geometry model used for Building 21, with the adiabatic surfaces being either the foundation or the roof, was built-up from the individual living units and the results of the two models combined into a duplex.

As previously described, for consistent value for modeling MELs, 1,273 kWh/yr produced a good baseline for the Beechwood duplex models. This value was determined from the questionnaire results. Figure 14 provides sample simulation results.

Figure 14: Source Energy End Uses for Five Models to Simulate Building 2 (Units 9-18)

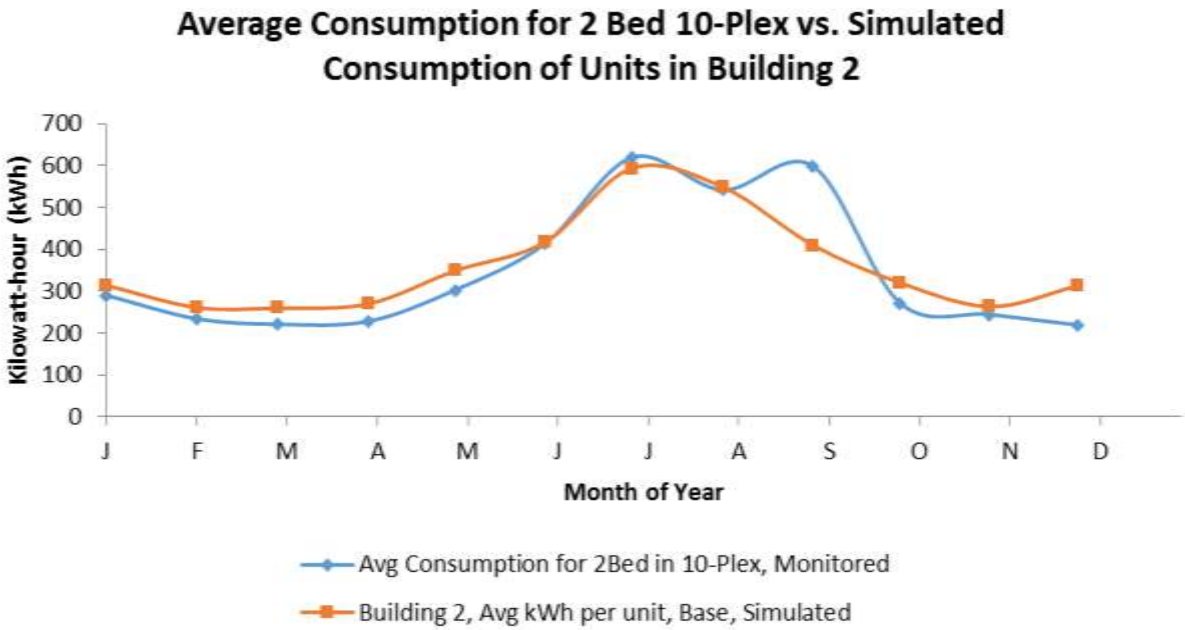


Source: Electric Power Research Institute

Simulation Results of Baseline Energy Models

The energy output of the BEopt v2.0.0.6 models were compared to the actual energy used by the apartments, as determined from utility bills obtained from the utilities with the occupants' permission. Figure 15 and Figure 16 show that the simulated energy use tracks the actual energy use very well, with the two data sets shown having an average monthly difference, across all the buildings' simulations, of ±5 percent (see Table 6 and Table 7). Figure 15 shows a comparison of the average simulated monthly electrical use of an apartment in Building 2 and the actual average electrical use of an apartment in Building 2 for 2011-2013. The calculated standard error for an average simulated month in Building 1 was 9 percent compared to the availability utility billing data; however, the average error of the monthly electrical use in all the models used in this study was 5 percent.

Figure 15: Comparison of Simulated and Actual Energy Use for Single Unit



Source: Electric Power Research Institute

The accuracy of the various models was calculated individually and for the Beechwood community as a whole. Table 6 shows the difference errors calculated for the different models, as well as an approximation of the overall error of the simulation of the site.

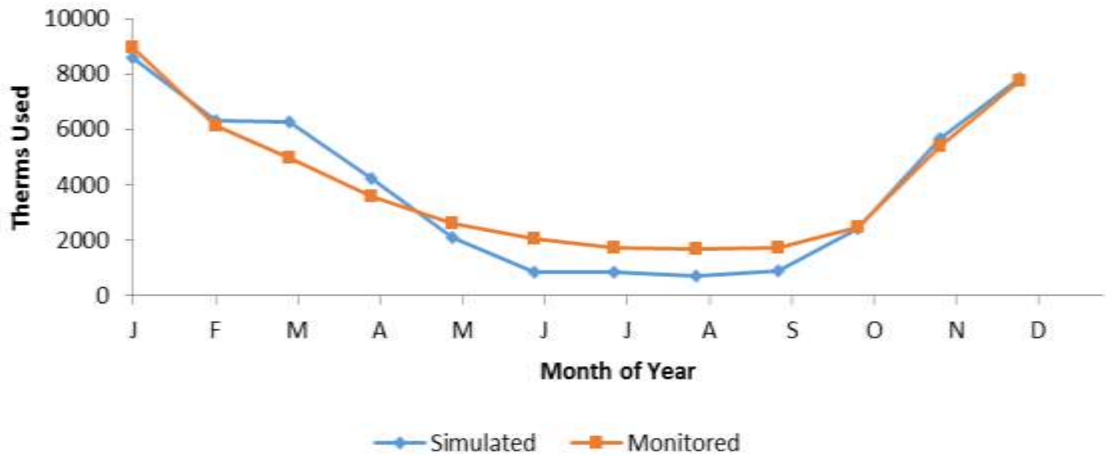
Table 6: Analysis Indicating 5 percent Match between Model and Southern California Edison Automated Metering Infrastructure Data

	Simulated, Avg Units, from 2nd Pass (kWh)					Monitored, Avg Unit (kWh)					Error, per unit, per month					
Monitored Monthly Schedule	Building 1, Avg kWh per unit, Base	Building 2, Avg kWh per unit, Base	Building 3, Avg kWh per unit, Base	Building 20, avg unit, Base, kWh	Building 21, avg unit, Base, kWh	Avg Consumption for 2Bed in 8-Plex, Monitored	Avg Consumption for 2Bed in 10-Plex, Monitored	Avg Consumption for 1Bed in 10-Plex, Monitored	Avg Consumption for 2Bed Duplex, Monitored	Avg Consumption for 3Bed Duplex, Monitored	Avg Consumption for 2Bed in 8-Plex, Monitored	Avg Consumption for 2Bed in 10-Plex, Monitored	Avg Consumption for 1Bed in 10-Plex, Monitored	Avg Consumption for 2Bed Duplex, Monitored	Avg Consumption for 3Bed Duplex, Monitored	Total
J	314	314	261	406	420	332	290	254	399	387	-5%	8%	3%	2%	9%	3%
F	262	261	218	334	343	259	234	207	361	329	1%	12%	5%	-7%	4%	3%
M	261	260	217	332	344	263	220	211	291	304	-1%	18%	3%	14%	13%	10%
A	267	270	217	285	403	232	227	201	230	289	15%	19%	8%	24%	40%	21%
M	335	349	276	304	512	341	302	289	283	370	-2%	15%	-4%	7%	39%	11%
J	397	417	337	362	589	514	414	373	409	612	-23%	1%	-9%	-12%	-4%	-9%
J	576	593	496	562	806	707	620	592	665	1,052	-19%	-4%	-16%	-15%	-23%	-16%
A	532	548	454	522	759	594	542	508	518	818	-10%	1%	-11%	1%	-7%	-5%
S	401	409	331	362	591	614	599	555	423	853	-35%	-32%	-40%	-15%	-31%	-30%
O	323	320	257	308	475	348	271	262	184	356	-7%	18%	-2%	67%	34%	22%
N	263	263	220	337	357	251	244	236	179	316	5%	8%	-7%	88%	13%	22%
D	313	313	260	405	419	296	219	196	312	324	6%	43%	33%	30%	29%	28%
	4,245	4,316	3,545	4,518	6,019	4,751	4,182	3,883	4,251	6,008	-6.2%	8.9%	-3.2%	15.4%	9.6%	4.9%

Source: Electric Power Research Institute

The Beechwood complex is master-metered for all natural gas used throughout the complex so there is no granularity to the available data regarding natural gas consumption in the complex and the natural gas use cannot be resolved with complete confidence either for the building or for the individual apartment level. The research team simulated every unique building type on the Beechwood campus, including the common area, and compiled these simulation results into a simulated master-metered natural gas use to correspond to the natural gas shown on the utility bill. Figure 16 compares the simulated gas consumption to the consumption recorded by Southern California Gas Company during 2011-2013. The calculated standard error of natural gas use of the Village at Beechwood for an average simulated month was 5 percent, compared to the available utility bill.

Figure 16: Comparison of Modeled and Actual Natural Gas Consumption



Source: Electric Power Research Institute

The accuracy of the natural gas simulation was also determined, in this case for the site. The result of the modeled natural gas consumption of the Beechwood community, compared to the average master-metered natural gas utility bill from 2010-2013, is shown in Table 7.

Table 7: Master Metered Natural Gas Bill for Beechwood Community (in Therms)

	Simulated	Monitored
January	8,587	8,972
February	6,303	6,145
March	6,265	4,949
April	4,221	3,592
May	2,114	2,602
June	858	2,054
July	823	1,743
August	686	1,677
September	876	1,703
October	2,435	2,474
November	5,652	5,391
December	7,863	7,736
Total	46,684	49,037
Difference		-4.8 percent

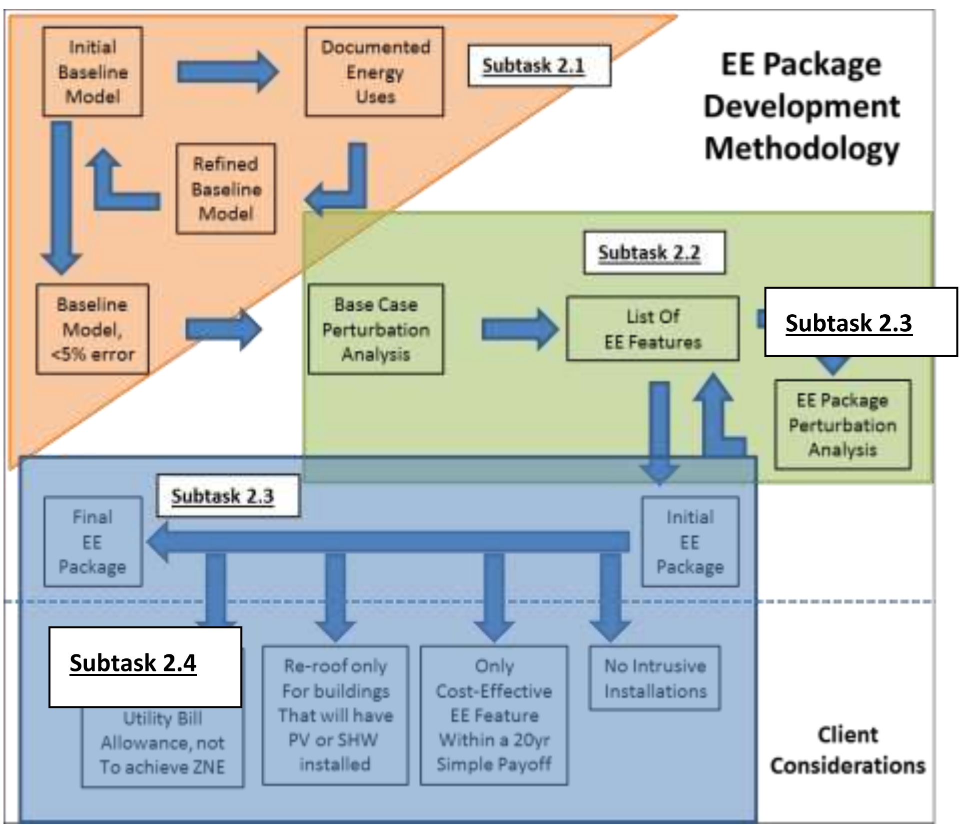
Source: Electric Power Research Institute

CHAPTER 3: Very Efficient Retrofit Package

This chapter describes the development of the very efficient retrofit (VER) packages targeting near-zero net energy and the process of evaluating financial strategies that could potentially make implementation cost-effective for property owners. The first section of the chapter describes the methods developed to select and rank energy efficiency measures of VER packages for the project. The second section describes the process used to evaluate the VERs and to select the most appropriate sets of efficiency measures and final VER package for the project.

The research team used the completed baseline model and simulation to build a library of efficiency measures that could be combined into a VER package from which the team could select and then test a cost-effective package of energy-saving measures. The package needed to be easy to install and as non-intrusive to the tenants as possible. The team used the results of the analysis to develop near-zero net energy packages, essentially VER packages plus solar generation. Figure 17 shows the process to develop VER packages, which included three separate subtasks.

Figure 17: Process Diagram for Energy Efficiency Package Development



Source: Electric Power Research Institute

Each of the subtasks 2.1, 2.3 and 2.4 was covered in separate reports to the California Energy Commission. The subtask 2.1 report covered the development of baseline models and simulation results for Beechwood; subtask 2.3 addressed the development of a method and system for ranking efficiency measures; subtask 2.4 described the final VER packages and the rationale for the packages.

Ranking Energy Efficiency Measures for Very Efficient Retrofit Package

The research team generated energy models of the different building types and estimated the energy usage of miscellaneous electric loads (MELs) using the methods described in Chapter 2.

Identification of Potential Very Efficient Retrofit Measures and Reasons for Rejections

Once the research team completed the baseline model and simulation, they built a library of energy efficiency (EE) measures for potential inclusion in a VERs package. EE measures were identified to reduce energy-use in all end-uses, including space heating, space cooling, heating, ventilation, and air conditioning (HVAC) and other fans impacting thermal comfort, water heating and hot water distribution, lighting, large appliances, and miscellaneous electricity and gas uses. After identification, metrics for each energy feature were recorded including potential energy savings, cost, availability, practicality, energy savings, and ease of installation.

Data collection was needed to develop packages that were nonintrusive. The level of intrusiveness of each potential retrofit feature was considered during the EE measure selection and ranking process, as was the overall intrusiveness of each package of measures. The retrofit process typically required a few days to complete at some level of inconvenience to the occupants. Some measures could only be installed while tenants were away during the day, while others required the apartment to be unoccupied and empty of furniture and decorations, most likely when apartments were vacant. Because The Village at Beechwood has historically operated at about 95 percent occupancy, the team rejected measures requiring vacant apartments due to scheduling and cost problems as well as the risk of delays in completing VERs packages due to waiting for a change in tenants. The team did, however, evaluate the measures in case limitations on installation could be eliminated in the future.

Sorting and Classifying Potential Very Efficient Retrofit Measures

Beyond those measures that required the apartment to be emptied, the first measure-sorting level was based on experience with each measure, including modeling parameters, availability, cost, practicality, difficulty or level of skill and training to install. Measures known to have failed one or more selection criteria were rejected from further consideration. For example, the team was instructed by the owner to not to consider installing foam-cladding on the walls due to the resulting cost, noise, and general disruption to tenants' lives. The remaining measures were evaluated using simulations to determine the relative efficiency savings for each measure after completion and calibration of the baseline. Each candidate efficiency measure was then added one at a time to the baseline model to determine the impact of that measure on energy use. The team included purchase and installation costs as well as notes regarding practicality and availability. The compiled data provided the basis for comparing different measures for inclusion in a VER package based on relative efficiency, cost, availability, and installation properties but did not measure any interactions between measures. A partial list of the findings of this sensitivity analysis is provided in Table 8.

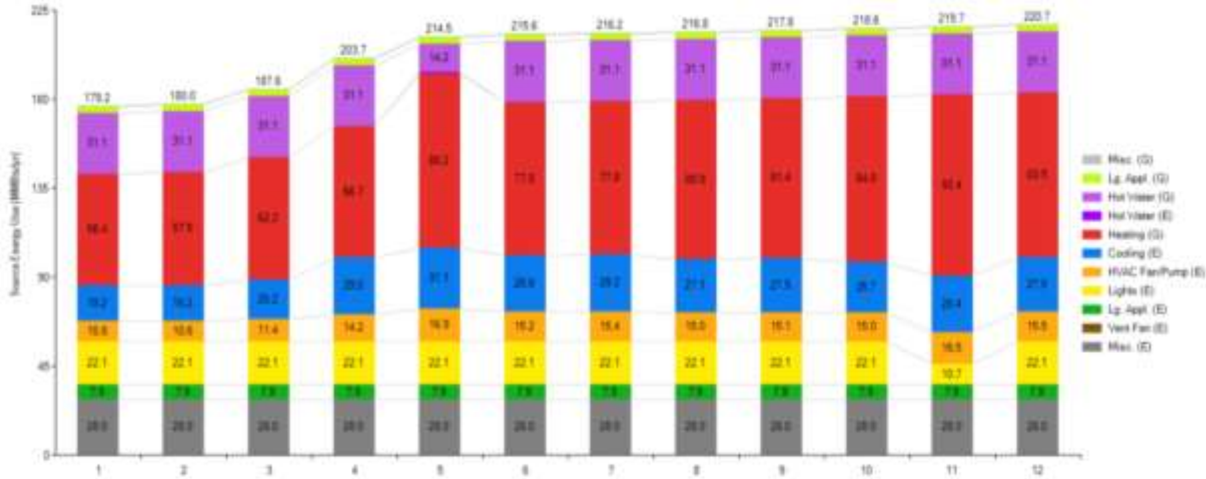
Table 8: Example Energy Impact Analysis

Single Feature Replacemet #	Base Case Single Feature Replacement Package
1	R-20 XPS Roof
2	Ducts in Conditoned Space
3	R8 Ducts, 7.5% Leakage
4	3.0 ACH50
5	56 sqft SHW
6	8.4 ACH50
7	0.29 / 0.31 Windows
8	Duct Sealing
9	R-13, Gr. 1 Walls
10	Radiant Barrier
11	R13, Gr. 3 Walls
12	100% LED
13	16 SEER AC (2-Stage)
14	0.96 EF Tankless Condensing DHW
15	0.21 / 0.21 Windows
16	Cool Roof
17	Min T24 Performance Frig & DW
18	2013-T24 Low Slope Roof
19	Home Energy Management Systen
20	2 Smart, Premium Ceiling Fans
21	Induction Cooktop
22	6 Smart, Premium Ceiling Fans
	Base Case, Building 20, avg unit

Source: Electric Power Research Institute

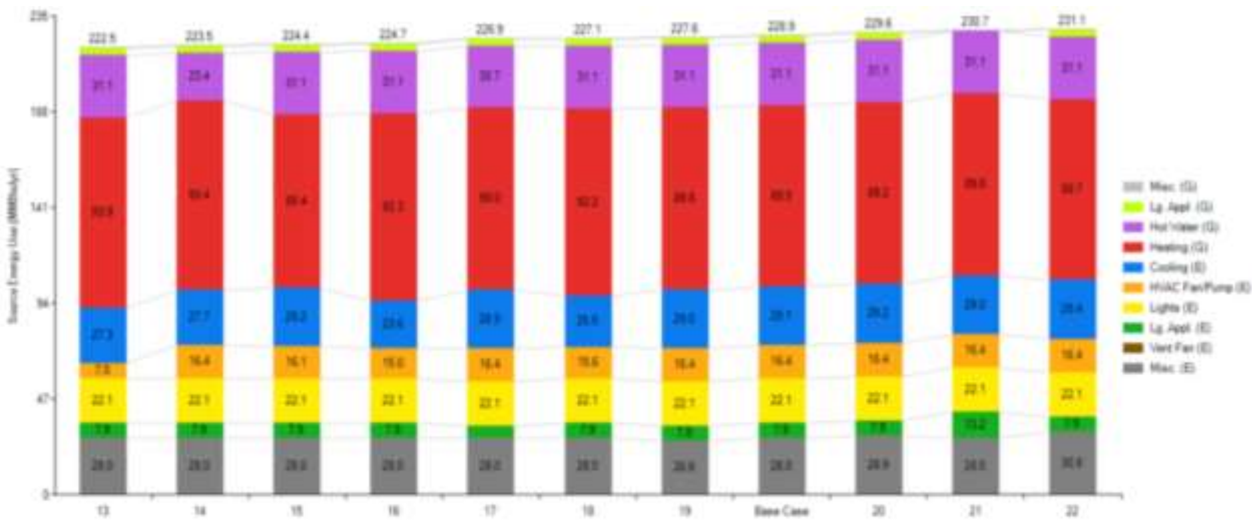
Figure 18 through Figure 21 show the simulation results as stacked-bars, providing the total apartment energy for each measure perturbation and its impact on the major energy end-uses. The single efficiency feature added to the base-case is identified by a number that corresponds to the feature number in the left-most column of Table 8, labeled “Single Feature Replacement #”. Note that, while interactions between measures were not available for analysis using this approach, there could be impacts on energy end-uses beyond that typically associated with each efficiency measure. For instance, a decrease in lighting energy produced by replacing all the lighting with compact fluorescent lamps (CFLs) or light-emitting diodes (LEDs) could also result in an increase heating energy and decrease in cooling energy because there was less waste-heat produced by the interior lighting.

Figure 18: Single-Feature Replacement Analysis with Very Efficient Retrofit Measures 1-12



Source: Electric Power Research Institute

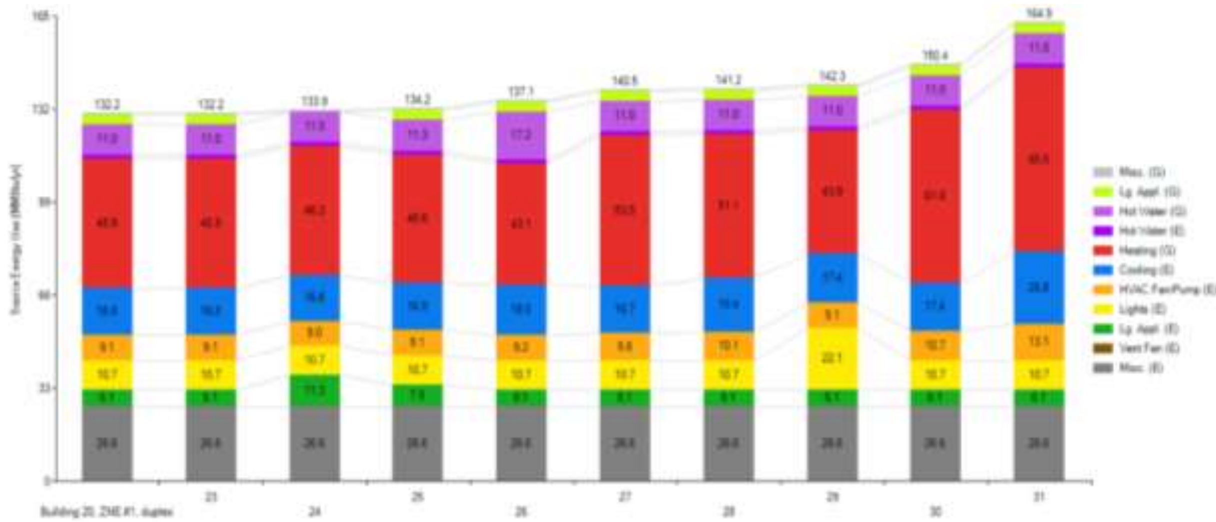
Figure 19: Single-Feature Replacement Analysis with Very Efficient Retrofit Measures 13-22



Source: Electric Power Research Institute

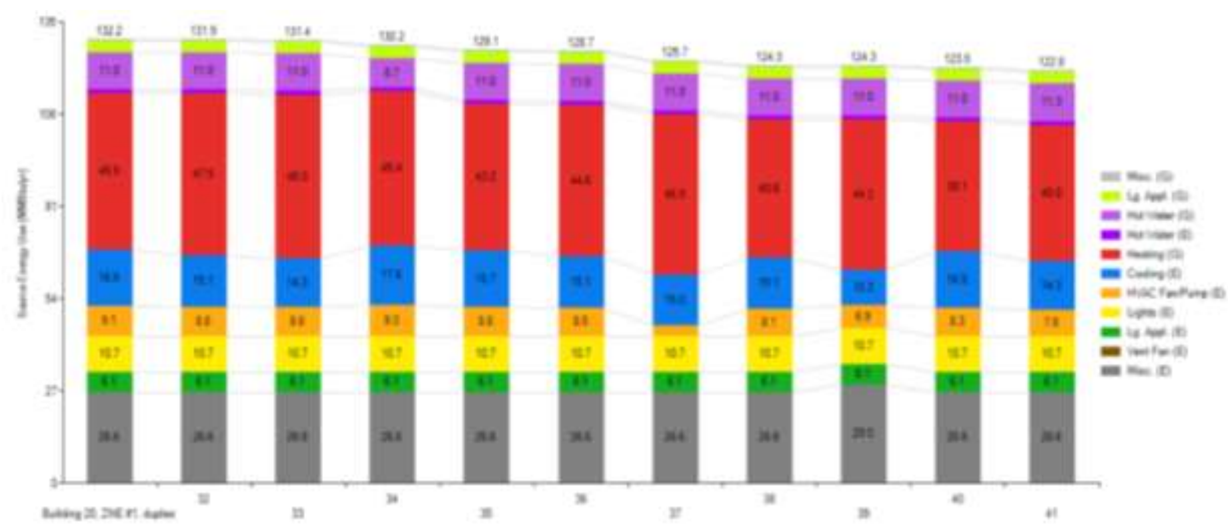
To further evaluate the features to find the best packages, a full VER package was established from the highest scoring features in the sensitivity analysis. The contribution of each feature to the VER was evaluated by simulating the building with a large number of the most cost-effective features included, then removing and replacing each measure, one at a time, with all others remaining. This single feature replacement analysis, here called “perturbation analysis”, provides insight into feature contributions when applied as a group and the interactions between measures. This approach, unlike the sensitivity analysis, brings out some of the measures’ interactions because when an individual measure is removed or downgraded to the baseline value, the amount of interaction is reduced or eliminated. The sensitivity analysis was performed on features 1-41, with a list of the findings provided in Table 9 and Table 10.

Figure 20: Single-Feature Replacement Analysis with Very Efficient Retrofit Measures 23-31



Source: Electric Power Research Institute

Figure 21: Single-Feature Replacement Analysis with Very Efficient Retrofit Measures 32-41



Source: Electric Power Research Institute

The simulation results showed the most promising measures were envelope tightening and low leakage ducts inside the conditioned space because of large energy savings, relatively low cost, and relatively low level of intrusiveness. Although these measures require occupants to vacate their apartment during normal working hours while construction is taking place, they can occupy their apartment in the evenings and overnight. Additional measures that provided adequate savings in the sensitivity analysis but were not on the short-list of measures (such as R-20 roof and higher-efficiency HVAC systems) because they were more expensive, required an unacceptable method of installation such as replacing features that are only half-way through their anticipated life, or were too intrusive to install.

Table 9: Source Energy and Cost Impacts of Single Features Tested in Perturbation Analysis

Single Feature Replace-ment #	Base Case Single Feature Replacement Package	Source Energy Use (s-Mbtu/yr)	% Source Energy Savings	Cost of Feature	Cost : Benefit ($/kBtu)	Annual Estimated Change in Utility Bill	Simple Payoff (Years)	Used in Initial ZNE Packages?	Notes
1	R-20 XPS Roof	179.2	22%	$ 4,871	$ 0.10	$ 453	11	Y	Only used with PV install
2	Ducts in Conditoned Space	180.0	21%	$ 4,871	$ 0.10	$ 448	11	Y	1st Choice for Ducts
3	R8 Ducts, 7.5% Leakage	187.6	18%	$ 1,949	$ 0.05	$ 378	5	Y	2nd Choice for Ducts
4	3.0 ACH50	203.7	11%	$ 2,214	$ 0.09	$ 210	11	Y	Only used in duplex
5	56 sqft SHW	214.5	6%	$ 2,885	$ 0.20	$ 102	28	Y	
6	8.4 ACH50	215.6	6%	$ 1,476	$ 0.11	$ 111	13	Y	
7	0.29 / 0.31 Windows	216.2	5%	$ 5,140	$ 0.41	$ 104	49	N	
8	Duct Sealing	216.8	5%	$ 2,406	$ 0.20	$ 108	22	Y	3rd Choice for Ducts
9	R-13, Gr. 1, Cellulose Walls	217.8	5%	$ 4,826	$ 0.44	$ 98	49	N	
10	Radiant Barrier	218.6	4%	$ 494	$ 0.05	$ 98	5	**N**	Denied by contactors, due to roof type
11	R13, Gr. 3, Cellulose Walls	218.5	5%	$ 4,826	$ 0.47	$ 92	53	N	
12	100% LED	219.7	4%	$ 1,045	$ 0.11	$ 113	9	Y	
13	16 SEER AC (2-Stage)	222.5	3%	$ 1,200	$ 0.19	$ 86	14	**N**	Current AC has not met expected life
14	0.96 EF Tankless Condensing DHW	223.5	2%	$ 910	$ 0.17	$ 48	19	Y	Only in duplex
15	0.21 / 0.21 Windows	224.4	2%	$ 5,188	$ 1.18	$ 36	143	N	
16	Cool Roof	224.7	2%	$ 1,476	$ 0.36	$ 56	27	**N**	Current Roof has not met expected life
17	EnergySTAR Frig & DW	226.8	1%	$ 1,934	$ 0.97	$ 23	86	**Y**	Incentivized, Potential for more savings
18	2013-T24 Low Slope Roof	227.1	1%	$ 4,871	$ 2.77	$ 29	169	N	
19	Home Energy Management Syste	227.6	1%	$ 600	$ 0.50	$ 15	41	**Y**	Potential for 2.5x savings
	Base Case, Building 20, avg unit	228.8							
20	2 Smart, Premium Ceiling Fans	229.6	0%	$ 800	$ (0.99)	$ (9)	-86	N	
21	Induction Cooktop	230.7	-1%	$ 1,879	$ (1.07)	$ (32)	-58	N	
22	6 Smart, Premium Ceiling Fans	231.1	-1%	$ 2,400	$ (1.08)	$ (28)	-86	N	

Source: Electric Power Research Institute

Table 10: Perturbation Analysis of the Very Efficient Retrofit Case

Feature #	VER Case Single Feature Replacement Package	Source Energy Use	% Source Energy	Cost of Feature	Cost : Benefit	Annual Estimated	Simple Payoff
23	Ducts Sealed to 7.5% Leakage, not in Conditoned Space, no insulation	164.9	-25%	$ 2,406	$ (0.07)	$ (153)	-16
24	Envelope not sealed (14.1 ACH50)	150.4	-14%	$ 2,214	$ (0.12)	$ (77)	-29
25	No LED or CFL lighting (original lighting)	142.3	-8%	$ 70	$ (0.01)	$ (60)	-1
26	Ducts Sealed to 7.5% Leakage, not in Conditoned Space, R8 duct insulation	141.2	-7%	$ 4,871	$ (0.54)	$ (42)	-116
27	Envelope Sealed to 8.4 ACH50	140.5	-6%	$ 1,476	$ (0.18)	$ (34)	-43
28	No 0.96 EF tankless condensing DHW	137.1	-4%	$ 910	$ (0.19)	$ (22)	-42
29	No EnergySTAR Refrigerator or Dishwasher	134.2	-2%	$ 1,934	$ (0.97)	$ (11)	-173
30	Induction Cooktop	133.9	-1%	$ 1,879	$ (1.11)	$ (15)	-126
31	No HEM	133.7	-1%	$ 600	$ (0.40)	$ (8)	-75
	VER Case	**132.2**	**0%**			**$ -**	
32	2013-T24 Low-Slope Roof	131.9	0%	$ 4,871	$ 0.05	$ 4	1101
33	Cool Roof	131.4	1%	$ 1,476	$ 0.02	$ 8	184
34	56sqft SHW	130.2	2%	$ 2,885	$ 0.03	$ 7	436
35	0.21 / 0.21 Windows	129.1	2%	$ 5,188	$ 0.05	$ 13	394
36	Radiant Barrier	128.7	3%	$ 494	$ 0.00	$ 18	27
37	16 SEER AC (2-Stage)	125.7	5%	$ 1,200	$ 0.01	$ 39	31
38	R15, Gr. 3, 2x4 16" o.c. Walls	124.3	6%	$ 2,431	$ 0.02	$ 36	67
39	Ceiling Fans, Smart, High Eff, 100% Coverage	124.3	6%	$ 5,834	$ 0.06	$ 42	138
40	0.29 / 0.31	123.5	7%	$ 5,140	$ 0.05	$ 37	139
41	R20 XPS Roof or	122.8	7%	$ 4,871	$ 0.05	$ 44	111
41b	R15 Ballasted Roof Sections	122.8	7%	$ 2,373	$ 0.02	$ 44	54

Source: Electric Power Research Institute

Roof insulation was initially evaluated both as R-20 rigid foam underneath and as part of a re-roof. This combination is not practical because the existing roofs are in good condition and estimated to have half their life remaining (about 15 years), and it is prohibitively expensive to replace and add foam mid-term. However, it is still unclear whether this approach could be employed on Building 3, which would be retrofitted with solar hot water collectors, making a re-roof practical to avoid having to remove the solar collectors within their useful life. Similarly, although higher efficiency HVAC units would be cost-effective as a replacement for units at the end of their useful lives, the HVAC units are also at about half their life, having been replaced at least once. Therefore, the resulting economics are not sufficiently favorable to LINC Housing, LLC (LINC) to go to the expense of renting a crane to replace units that expected to last another 8-10 years.

Roof insulation was also been reviewed using R-15 ballasted roofing insulation modules. These are rigid foam insulation with a cover of lightweight cement to protect the foam and provide weight to keep it on the roof. This insulation approach could be used on all the buildings with the advantage of extending the life of the existing roof, which would be covered and protected from ultraviolet light and high heat. The undersides of the roof-insulation modules are grooved to allow water to run off and not be trapped underneath the insulation modules. Also, the modules can be cut to fit around the HVAC systems and other obstacles. Discussion of this measure is warranted to determine the best method to value the delay in re-roofing from a possible 10-year to 20-year horizon.

There were discussions regarding the underground piping from the central boilers to the multiplexes: whether it is insulated, and, if not, the size, length, and buried-depth of the plumbing. If not insulated, the losses are considerable and, once exposed, the pipes are simple to insulate. However, the costs of exposing the pipes are also unknown, and if exposed using machinery, there is risk of damaging the piping. While this was an interesting and potentially cost-effective measure, additional discussion and data are required.

Table 11 provides the initial matrix of packages based on simulation results prior to verification via the pilot installation and ensuing analyses. The baseline features are in red, upgraded measures in blue, and the additional option of rooftop foam-modules in green.

The initial EE measures of the VER package consisted of:

- Tightly-sealed ducts that are heavily insulated so as to thermally isolate them (modeled as being in conditioned space).
- Low air-infiltration via air-sealing the envelope.
- Solar water heating for the multiplexes, including a re-roof on the building that will support the solar collectors (with or without adding foam).
- Condensing boilers for the first 100-gallon hot water backup for the multiplexes' solar domestic hot water system.
- Condensing tankless water heating for the duplexes.

Table 11: Final Very Efficient Retrofit Package Descriptions from Perturbation Analysis

Category Name	Beechwood 2 Bed Duplex Base Case	Building 1, Units 1 - 8	Building 2, Units 9 - 18	Building 3, Units 19 - 28	Building 3, Units 19 - 28	Building 20 Duplex, Units 83 - 84	Building 20 Duplex, Units 83 - 84	Building 21 Duplex, Units 85 - 86 (3bd)	Incremental Cost, per each unit	Units of Costing	Reference for Costs	Notes
ZNE Package #	Baseline	1	1	1	2 (alternative package)	3	4 (SHW)	4 (SHW)				features highlighted red same as basecase
Misc Electric Loads	1273 kWh/yr per unit	1273 kWh/yr per unit, with HEM [5% Savings]	1273 kWh/yr per unit, with HEM [5% Savings]	1273 kWh/yr per unit, with HEM [5% Savings]	1273 kWh/yr per unit, with HEM [5% Savings]	1273 kWh/yr per unit, with HEM [5% Savings]	1273 kWh/yr per unit, with HEM [5% Savings]	1273 kWh/yr per unit, with HEM [5% Savings]	$ 600.00	per unit	Kango	Add Tstat, incr. savings to 12%?
Unfinished Attic	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	R-15 Ballasted Foam Roof Membrane (Em = 0.4 , Abs = 0.8)	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	Ceiling, 2" fiberglass, R-6.4, gr. 3	$ 3.26	per sqft roofspace	Tclear	*doesn't include installation
Insulation Blown into reachable attic bays	2" fiberglass batts	7" blown R-24 apprx 25% 2nd floor	7" blown R-24 apprx 25% 2nd floor	7" blown R-24 apprx 25% 2nd floor		7" blown R-24 apprx 25% 2nd floor	7" blown R-24 apprx 25% 2nd floor	7" blown R-24 apprx 25% 2nd floor	$ -	25% unit roof area	BIRA	included in ducts
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	Sealed to 3.0 ACH50	$ -	per sqft CFA	BIRA	*included in ducts
Refrigerator	18 cu ft., EF = 15.9, top freezer	18 cu ft., EF = 21.9, SCE ESA? top freezer	18 cu ft., EF = 21.9, top freezer	18 cu ft., EF = 21.9, top freezer	18 cu ft., EF = 21.9, top freezer	18 cu ft., EF = 21.9, top freezer	18 cu ft., EF = 21.9, top freezer	18 cu ft., EF = 21.9, top freezer	$ -	per unit	SCE ESA; made b4 1998?	$975 RS Means; paid by SCE in ESA Program
Dishwasher	318 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	290 Annual kWh	$ 959.00	per unit	2013 RSMeans	
Lighting	100% Incadescent	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	100% LED (or CFLs from SCE), Hardwired & Plugin	$ -	per unit	CFL free SCE; LED $7/lamp	How many from SCE?
Ducts	Uninsulated, 32% Leakage	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	R22, 6% total leakage	$ 2,464.00	Per unit	BIRA	See Task 2.4 Report: ave of bottom-up costing and Top-down costs-adjustments
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF) Duplex: 40gal Storage (0.62 EF)	Multi: 3-100gal Boiler Bkup (0.94, 0.80, 0.80 EF)	Multi: 3-100gal Boiler Bkup (0.94, 0.80, 0.80 EF)	Multi: 3-100gal Boiler Bkup (0.94, 0.80, 0.80 EF)	Multi: 3-100gal Boiler Bkup (0.94, 0.80, 0.80 EF)				$ -		Kango	
						Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)	$ 910.00	per unit	Kango	
Solar Water Heating	None	Everyday Energy; 24 panels total, evacuated tube drainback	Everyday Energy; 24 panels total, evacuated tube drainback	Everyday Energy; 24 panels total, evacuated tube drainback	Everyday Energy; 24 panels total, evacuated tube drainback				$ 1,279.84	per unit	Kango	
							SunEarth EC 40 collector w/ 80 gal Rheem heat exchange tank	SunEarth EC 40 collector w/ 80 gal Rheem heat exchange tank	$ 2,884.50	per unit	Kango	Solar DHW on duplexes?
Conditioned Floor Area, per unit	-	738	738	582	582	738	738	1017				
Cost, Per Unit	-	$ 5,303	$ 5,303	$ 5,303	$ 7,200	$ 4,933	$ 7,818	$ 7,818				

Source: Electric Power Research Institute

There was also an option to include solar water heating on the duplexes. The packages included replacing all lamps with either LEDs or CFL's (CFLs being available through Southern California Edison's [SCE] Energy Savings Assistance [ESA] Program), new, more efficient refrigerator (available through the SCE's ESA Program for refrigerators manufactured prior to 1999), programmable communicating thermostats, and Home Energy Management systems (HEMS) for each apartment.

The matrix of the VERs packages provides the measures and their costs, which were used to estimate a simple payback period for the packages. A summary of these estimates is shown in Table 12. The estimated cost of solar panels was $1/watt (W), but installed cost of photovoltaics (PV) after rebates is closer to $2/W). In combination with the simulation results, the cost/benefits can be calculated for the key packages. Once the final packages were chosen, firm costs could be determined from bids (possibly resulting in some reassessments). The resulting final features, their energy savings estimates and costs can be used to develop different possible financial models that may be used to alter rent calculations or change some cost/savings assumptions in existing financial models, or even development of new models and policies.

During the initial assessment, it was determined that the ducts were old flex duct, with no inner lining and considerable dust and dirt. As a result, they are leaky and thermally poor. A "pilot" installation and evaluation of proposed improvements in the ducts and of air-sealing the envelope was conducted to evaluate a novel approach to thermally-isolating the ducts, which the team posits will perform as well as ducts in conditioned space. The results of the pilot study were a key factor in determining the final VERs package.

Table 12: Economic Analysis of Very Efficient Retrofit Packages with and without Photovoltaics

Building #	Base Case Electrical Bill (CARE)	Base Case Natural Gas Bill ($0.91 / therm)	VER Case Electrical Bill (no PV)	VER Package Cost, w/o PV	VER Case Natural Gas Bill ($0.91 / therm)	Annual Utility Bill Savings	Simple Payoff (years)	VER Case Electrical Bill (PV installed)	VER PV Size, per unit	VER Package Cost, w PV ($1/W)	VER Case Natural Gas Bill ($0.91 / therm)	Annual Utility Bill Savings	Simple Payoff (years)
20	$411.03	$ 321	$278	$ 7,884	$ 257	$ 197	31	$146	0.85	$ 8,736	$ 257	$ 329	27

Source: Electric Power Research Institute

Pilot Evaluation of Very Efficient Retrofit Package

Pilot installations of the package selected for use in the occupied apartments were conducted to verify effectiveness of packages before installing into the rest of the apartments.

A pilot retrofit installation was conducted in July 2014 to test the removal, replacement, sealing, and thorough insulation of the ducts, as well as evaluate how well the apartments could be air-sealed. The ducts were exposed by removing the dropped ceiling that encloses the duct chase. The ceilings in the test apartments were examined and determined to likely contain asbestos, so a certified asbestos abatement professional performed the removal and disposal of the ceiling materials. As determined in the preliminary evaluations, the existing ducts were old, poorly sealed, poorly insulated flex-ducts. After gaining access, the ducts were removed and replaced with new, R-8 flex-duct, which was carefully installed and sealed to minimize leaks. The new ducts were also encased in insulation prior to fitting the opening with new drywall.

A main purpose of the pilot was to ensure that the proposed approach would provide a relatively easy method to replace the current duct system with tight, super-insulated ducts, garnering savings similar to ducts in conditioned space. The pilot was successful in this regard.

Another key efficiency measure was sealing the envelope. This was done by hand in the pilot. The package will also include solar water heating for the multiunit buildings, and a condensing water heater for duplexes, a communicating thermostat, Home Energy Management system, none of which were evaluated in the pilot.

Installed measures included utility ESA measures, along with measures paid for with the Public Interest Energy Research grant funds. Southern California Gas Company's ESA program paid for weatherization including weather-stripping, door shoes/sweeps, door replacements, switch and outlet gaskets, minor repairs to the interior that may affect energy performance, and locksets. The ESA program also paid for water measures such as faucet aerators, shower heads, and thermostatic shower valves. A similar electric program delivered by SCE allowed for refrigerator replacement (for refrigerators manufactured in 1998 or before), interior CFL light bulbs, and smart power strips for homes with media/computer setup. These additions helped reduce the overall cost of the retrofit and increased its cost-effectiveness.

The pilot site evaluation required the same process as the full size retrofit conducted later in the project and employed the same retrofit contractor. The process was conducted in two apartments and included the cost to move from poorly insulated, leaky ducts to air-tight, very-well insulated ducts, equivalent to putting the ducts "in conditioned space" (an equivalent R-value that will produce a performance equal to that of having the ducts in a conditioned area), and air-sealing the envelope. During the pilot, once the duct chase area was opened, it was determined that connecting ceiling bays were available for blowing-in insulation, followed by sealing air-paths between the building interstitial spaces and the duct chase, which was a field-added addition to the scope and therefore likely a somewhat higher cost than if planned from the beginning of the pilot. An estimated 180 square feet of ceiling insulation was installed in the second-floor apartment. The asbestos removal may not be necessary in similar buildings built after 1980; although there were none in this project, this might apply to similar buildings elsewhere.

In addition to standard air-leakage tests of the envelope and the ducts, before and after the retrofit, a temperature probe with on-board storage was installed in the collar connecting the kitchen supply duct to the grill, recording air temperatures in the duct both before and after the retrofit. This provided a simple approach to provide a basis for comparing the actual effectiveness of the retrofit to the simulation results. Both duct and envelope leakage were measured before ("test-in") and after ("test-out") the retrofits were performed. These data provided clear demonstration that prior to the retrofits, both the envelope and the ducts had substantial leakage, and that post-retrofit, the contractor had achieved the target air sealing of both envelope and ducts. To visualize the leakage in the pre-retrofit ducts, smoke-tests were performed. The results of the test-in and test-out leakage measurements are summarized below, along with pictures of the ducts, the smoke tests, and thermal imaging prior to removal. Pre-retrofit leakage values of around 22 percent leakage were measured during test-in:

> *<u>Test In: Duct Leakage</u>*
>
> *Apt. 17 – 2-ton unit, (177) cubic feet per minute (CFM) @25p, 22.1 percent leakage*
>
> *Apt. 18 – 2-ton unit, (181) CFM @ 25p, 22.6 leakage*

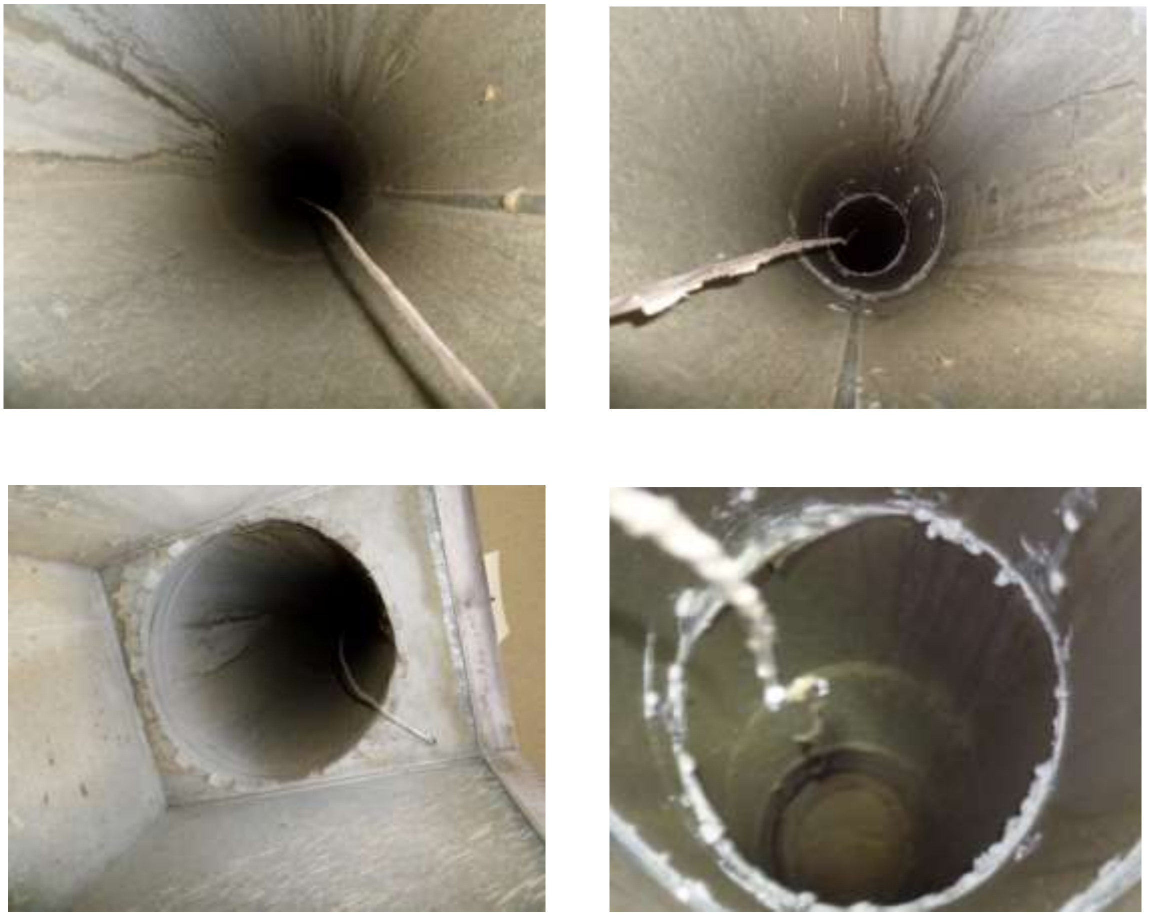
During the pilot, when the ducts were exposed with the ceiling removed, and prior to their removal and retrofit, the duct leakage was visualized by smoke test and a thermal camera. Figure 22 shows a thermal view of a duct connecting to the main supply distribution box. The dark-blue areas on the screen of the thermal camera are cold air from the air conditioning unit leaking out into the duct chase. These were typical of the installations in both apartments. Figure 23 shows a duct-collar connecting to the duct-distribution box. The round duct collar has metal tabs that should be alternating on each side of the distribution box, to hold it securely in place, then sealed with mastic. The tabs are clearly visible surrounded by cold, conditioned air leaking all around the connection.

Figure 22: A Screen-Shot of Thermal Camera

Source: Electric Power Research Institute

Visual inspection of the original ducts found tears in the flex duct and the leakage was noticeable with the thermal imaging camera. The thermal camera also detected leakage at register boots in both apartments. Smoke tests, performed separately in each apartment, resulted in smoke filling the chase cavity and hallway area. Visual inspections of the inside of the return in apartment 17, using a flashlight found gaps at the connections of the ridged pipe of the return-duct system (Figure 23). The return from the downstairs apartment runs through the interstitial space around the upstairs apartment, and when the smoke test was performed on the downstairs apartment, smoke leaked into the upstairs apartment (with the ceiling removed) via the leaks and interstitial-space connections.

Figure 23: Application of Expansive Foam to Ducting Joints for Sealing



Source: Electric Power Research Institute

Apartment 18 had a high leakage at the supply plenum; this was confirmed by how quickly the hallway was filled with smoke and by visually finding poor connections at all the distribution connections at the supply, with large gaps after the removal of insulation wrap and flex-ducts.

All the existing flex duct was removed and replaced with new, R-8 flex duct that was connected to register boots, “Y” connectors, and transition collars using standard practices as defined by the Air Diffusion Council and required by the California investor-owned utilities’ efficiency programs. Corrections and repairs to the steel connector parts of the duct systems in apartments 17 and 18 were made using Mastic, which was used to seal all register boots, and the inner and outer joints of the plenum sheet metal. The reducers and “Y” rigid sheet metal connectors, were also treated this way, sealing all accessible seams in sheet metal connectors and boxes. The supply plenum was taken apart at the distribution cut-out collars which were repaired, reinstalled, and sealed. Several of the connection gaps in the return in apartment 17 were sealed with foam using a long quarter-inch tube connected to a foam canister. Using this technique, the team was able to reach and seal return-pipe joints approximately 8’ inside of a 20’ run of 14” rigid pipe.

New R-8 ducts of 6”, 8”, and 10” diameter were installed to replace the same inner-diameter size of original ducts. Boots and distribution collars were sprayed with adhesive to improve duct bonding to sheet metal; the junction of duct-to-collar was made with approved tape, and nylon zip-ties were applied over the taped-junction to provide mechanical strength and a fully secure seal. The post-retrofit leakage was as follows:

Duct Test after sealing in Apt. 17 - 18

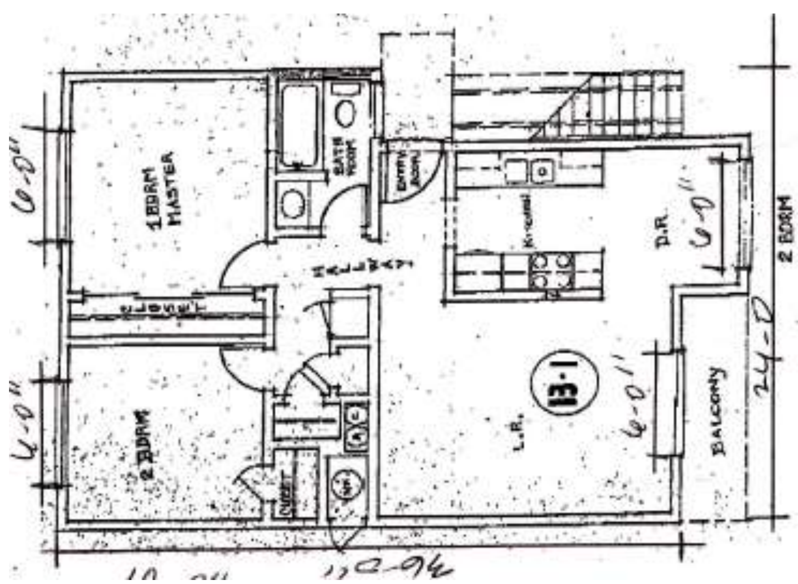
Apt. 17 - 2-ton unit, (118) CFM @ 25p, 14.7 percent leakage

Apt. 18 - 2-ton unit, (110) CFM @ 25p, 13.7 percent leakage

With the drop-ceiling below the duct plenum removed, it was discovered that, in apartment 18, some ceiling bays between truss-members were accessible from the duct chase. The original 3” rockwool insulation (originally R-13) was in-place and there was 7” of air space in each bay, above the existing batt insulation. Loose-fill insulation was blown into these bays filling the available 7” of space, reaching as far into each accessible bay as possible. The addition of 7” of loose-fill fiberglass to the original R-13 batt provides total insulation of approximately R-22. The areas that were treated included the living room, and the two bedrooms, for a total area of approximately 182 square feet. This is a coverage of about 25 percent of the total ceiling area for a two-bedroom apartment, the total floor area for which is 732 square feet (Figure 24).

The air-path connections between the duct chase and ceiling bays, and other interstitial spaces were closed with R-19 batt and air-barrier material to stop air leakage between these different areas. R-19 batts were placed all around the edges of the duct chase, followed by application of additional blown fiberglass to, as much as possible, fill the drop-ceiling duct chase volume both in the hall and entryway. This additional insulation covering the ducts was approximated to be R-22.

Figure 24: Two-Bedroom Unit Floor Plan



Source: Electric Power Research Institute

The return cavity in apartment 17 was very difficult to reach with the fiberglass blowing-machine hose, due to framing obstruction, and, due to the asbestos in the ceiling, there was no opportunity to increase the opening. Thus, it was not possible to fill the return chase with insulation. During the actual retrofit, this problem could be solved as follows: Additional acoustic ceiling should be removed in the hall closet, approximately 2' x 3' on ceiling and 8" x 24" on wall near return. Which closet (linen or coat closet) and actual dimensions may vary by apartment types and locations. The return and supply chase cavity in apartment 17 can also be accessed by apartment 18 walk in closet by removing drywall approx. 12" x 15" opening.

Envelope air-leakage paths were consistent in apartments 17 and 18 as well as with experience in other buildings; leaks were found and sealed at the following locations:

- Interior and exterior outlets and switches
- Exhaust hood above stove at top of cabinet and filter screen of hood
- Exhaust fan in restroom
- Supply water lines and drain under kitchen sink at wall
- Around all windows and the sliding glass-door
- Smoke detector wall junction box
- Light junction boxes in bedrooms and hallways.
- Supply registers in living room, kitchen, bed rooms
- Bedroom 1 wall drain clean out for adjacent restroom

The following corrections were made in apartments 17 and 18 to reduce/eliminate air leakage at these locations:

- Electric outlet and switch box-covers: Installed foam gaskets cover plates.[2]
- Kitchen exhaust fan and vent pipe: foam sprayed around large gap at top of cabinet vent cut out and damper was installed in exhaust vent and foil taped at connecting joints of vent pipe.
- Foam sprayed around supply lines and drain at drywall cutout openings.
- Caulking at windows metal frame and drywall edges.[3]
- Exhaust fan in restrooms unable to correct due to manufacture function design.
- Caulking along sliding door frame edges.
- Foam sprayed around box and drywall gap and cut out inside box.

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[2] Not all wall outlets were done in #18 due to large furniture in living room and bedrooms.

[3] The water drain openings at bottom of windows have no hinge covers, a manufacture design.

- Light fixture box and drywall gap sprayed with foam.
- Bedroom 1 used spray foam in gap around clean out and drywall.
- Supply register boot sealed with foam spray in gap between drywall and boot edge.

After completion of the duct replacement, replacement of the drop-ceiling, and envelope sealing as detailed above, "Blower Door" tests were performed to measure envelope leakage post air-sealing sealing.

Blower-Door Air Tightness test results, post retrofits:

Apt. 17: Square feet (842), Volume (5692 cubic feet), Climate Zone (4), N-factor (24)

Initial Intake Reading	810 CFM @ 50p
Final Reading	227 CFM @ 50p

Apt. 18: Square feet (842), Volume (5692 cubic. feet), Climate Zone (4), N-factor (24)

Initial Intake Reading	957 CFM @ 50p
Final Reading	258 CFM @ 50p

Very Efficient Retrofit Package Options for Occupied Apartment Units

Building energy models for occupied apartments were constructed in BEopt v2.3.0.1. A wide variety of individual efficiency measures were evaluated to build VERs packages. The VER options for two of the largest contributors to energy losses, and therefore those that provide the largest opportunities for savings were evaluated in the pilot, described earlier in this document. The pilot proved the duct sealing and insulating approach, as well as the envelope air-sealing performed as modeled. The combined simulation and pilot study results provided the research team with four different VER packages options that LINC could install. The differences between options center around the domestic hot water system retrofit options as follows:

- Option 1: include a solar hot water system, a reroof of Building 3 including addition of approximately R-21 roof insulation prior to installation of the solar hot water system, and replacement of the existing domestic hot water system distribution piping.
- Option 2: identical to Option 1 except no re-roof or installation of roof insulation.
- Option 3: instead of solar hot water system, replace the central storage boilers with a central battery of instantaneous water heaters and install a single 100-gallon backup storage tank per manufacturer's recommendations; also replace domestic hot water system pipes.

- Option 4: abandon the central boiler system and underground domestic hot water system distribution piping and in their place add a series of instantaneous water heaters to each building, sufficient to handle the domestic hot water system load from each building.

After all the models of occupied apartments needed to construct the VER options were rendered (17 models per option, 68 models total), the options were organized into a table according to the relative site energy savings for each (Table 13).

Table 13: Example of Annual Per-Unit Savings Calculation

			Base Case						VERS Case, opt 1					
			Utility Bill Data	BEopt v2.3.0.1 Models										
Building #	Apt #s	Total # of Units	kWh used per unit		kWh per 2 units	% Difference from Bill Data, per unit	Therms per year, Per unit	Therms per year, Per 2 units	kWh used per yr, per unit	% kWh Savings per unit	kWh per 2 units	Therms per year, Per unit	Therms per year, Per 2 units	% therms saved per unit
1	1,3	2	4,939	4,445	8,889	-10%	354	708	3,615	19%	7,230	123	246	65%
1	2,4	2	4,939	4,637	9,274	-6%	309	618	3,641	21%	7,282	104	207	66%
1	3,7	2	4,939	4,637	9,274	-6%	309	618	3,641	21%	7,282	104	207	66%
1	4,8	2	4,939	4,455	8,910	-10%	362	724	3,618	19%	7,236	128	255	65%
2	9, 11	2	4,438	4,439	8,878	0.02%	362	723	3,721	16%	7,442	153	306	58%
2	10, 12	2	4,438	4,708	9,416	6%	309	618	3,763	20%	7,527	126	251	59%
2	13, 14	2	4,438	4,910	9,819	11%	256	513	3,764	23%	7,529	126	251	51%
2	15, 17	2	4,438	4,708	9,416	6%	309	618	3,763	20%	7,527	126	251	59%
2	16, 18	2	4,438	4,466	8,932	1%	347	695	3,641	18%	7,283	123	246	65%
3	19, 21	2	3,908	3,897	7,793	-0.3%	314	628	3,205	18%	6,410	114	227	64%
3	20, 22	2	3,908	3,887	7,773	-1%	287	574	3,186	18%	6,372	93	186	68%
3	23, 25	2	3,908	3,887	7,773	-1%	287	575	3,187	18%	6,375	93	186	68%
3	24, 26	2	3,908	3,887	7,773	-1%	287	574	3,186	18%	6,372	93	186	68%
3	26, 28	2	3,908	3,915	7,829	0.2%	302	604	3,295	16%	6,589	105	209	65%
20	80, 81	2	4,632	4,487	8973	-3%	318	636	3,589	20%	7,178	185	371	42%
21	85	1	7,237	7251	n/a	0.2%	466	n/a	4,839	33%	n/a	288	n/a	38%
21	86	1	7,237	7153	n/a	-1%	514	n/a	4434	38%	n/a	310	n/a	40%
avg, per unit						**-0.9%**								

Source: Electric Power Research Institute

Due to the limitations of BEopt, the kWh/yr data in Table 13 were modified to be as correct as possible. Modifications included:

- The solar hot water system pump energy was subtracted from the kWh/yr for each apartment because it would be master-metered and therefore not be charged to the tenants.
- BEopt was unable to calculate the therms lost to the ground due to underground pipes so the team provided estimates using engineering principles, local weather, and other information. These estimates were only applied to models with underground pipes, including all cases in which underground domestic hot water system distribution pipes were replaced with new insulated underground pipes.
- The data in Table 13 was used to determine the accuracy of the model (compared to the kWh/yr of the utility bills) and to summarize the end use per apartment for use in a final table.

The final VER package table tracks the dollars per year spent on utility bills and the annual savings of the VERs package. An example of the final VER package table is shown in Table 14.

Table 14: Example of Energy and Cost Analysis for the Final Very Efficient Retrofit Package

Building	EE Cost ($/unit)	Annual	Gas Usage (Therm, $) Base	Gas VER	Gas Sav.	Elec. Usage (kWh, $) Base	Elec. VER	Elec. Sav.
Building 1	$ 4,660	Energy	333	114	219	4,543	3,629	915
		Cost	$ 307	$ 105	$ 201	$ 467	$ 373	$ 94
Building 2	$ 4,660	Energy	317	131	186	4,646	3,731	915
		Cost	$ 291	$ 120	$ 171	$ 478	$ 384	$ 94
Building 3	$ 4,660	Energy	295	99	196	3,894	3,212	682
		Cost	$ 272	$ 91	$ 180	$ 401	$ 330	$ 70
Building 20	$ 3,555	Energy	318	185	133	3,887	3,187	699
		Cost	$ 293	$ 170	$ 122	$ 400	$ 328	$ 72
Building 21	$ 3,555	Energy	490	299	191	7,202	4,637	2,566
		Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

Source: Electric Power Research Institute

The team constructed an energy and cost table for each zero net energy (ZNE) option and incorporated the total VERs costs and savings from all tables into a master table. The master table provides a basis for deciding which of the final VER options should be installed.

Individual worksheets for the cash flow for each VER option are calculated separately (four VER options, so four worksheets total, in this case). Table 15 provides an example of a cost table used in the worksheets. The gas savings per apartment from the "annual per-unit savings" worksheet were fed into a table in the cash-flow worksheet, shown as Table 16**.**

Table 15: Example of Feature-Cost Table Employed in Cash Flow Calculation

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)	Incremental Cost, per unit	Units of Costing
Misc Electric Loads	Unmonitored	Home Energy Management System					$ 600	per unit
Unfinished Attic	Ceiling, 2" cellulose, R-6.4, gr. 3	Ceiling, R7 batt	Ceiling, R7 batt	Ceiling, R7 batt	Ceiling, R7 batt	Ceiling, R7 batt	$ -	
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage					$ 2,500	per unit
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50					$ -	per sqft CFA
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Shared 100gal Boiler (0.80 EF)					$ -	per unit
	Duplex: 40gal Storage (0.62 EF)				Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)	$ 455	per unit
Hot Water Pipes	Multiplex: Uninsulated, underground	Replaced with new, 2" insulated pipes					$ 271	per unit
Solar Water Heating	None	Everyday Energy; Evacuated tube drainback					$ 1,289	per unit
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head		Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head	$ -	per unit
Refrigerator	18 cu ft., pre-1999	18 cu ft., new	18 cu ft., new		18 cu ft., new	18 cu ft., new	$ -	per unit
Lighting	Incadescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting					$ -	per bulb
Cost, per unit		$ 4,660	$ 4,660	$ 4,660	$ 3,555	$ 3,555	$ 144,702	per 32 units

Source: Electric Power Research Institute

The research team investigated cumulative payments made against a loan used to cover the installation of each package as well as the simple payoff that will occur when LINC uses grant money for the install. These payments (Table 17) were used to calculate the net cost or gain resulting from installation of the entire VER package into the occupied apartments. The table amortized payments and calculated the number of years to reach positive cash flow, the average annual savings over the loan period (20-year and 30-year loans), and the total amount paid against the loan. Similar tables were prepared for both 20-year and 30-year amortization schedules. Table 17 shows the 20-year “amortized payments” table for the occupied apartments of VER option #1.

Table 16: An Example of Annual Gas Savings for the Calculation Cash Flow

Annual Gas Bill Savings, per unit	**$ 201**	**$ 171**	**$ 105**	**$ 122**	**$ 175**		$ 4,761	**per 32 units**

Source: Electric Power Research Institute

Table 17: Very Efficient Retrofit Option #1 with 20-Year Amortization and 40-Year Cash Flow

	20yr Cash Flow, Ammortized							
	Year	Payment Due	Annual Gas Bill Savings, per unit (2.5% inflation)	Cumulative Payments	Annual Gas Bill Savings, per unit (2.5% inflation, 2.5% Price Escalation)	Cumulative Payments	Annual Gas Bill Savings, per unit (2.5% inflation, 4% Price Escalation)	Cumulative Payments
1	2015	$ (16,110)	$ 5,362	$ (10,748)	$ 5,362	$ (10,748)	$ 5,362	$ (10,748)
2	2016	$ (16,110)	$ 5,496	$ (21,361)	$ 5,630	$ (21,227)	$ 5,711	$ (21,147)
3	2017	$ (16,110)	$ 5,634	$ (31,838)	$ 5,912	$ (31,425)	$ 6,082	$ (31,175)
4	2018	$ (16,110)	$ 5,775	$ (42,173)	$ 6,208	$ (41,328)	$ 6,477	$ (40,807)
5	2019	$ (16,110)	$ 5,919	$ (52,364)	$ 6,518	$ (50,920)	$ 6,898	$ (50,019)
6	2020	$ (16,110)	$ 6,067	$ (62,407)	$ 6,844	$ (60,186)	$ 7,347	$ (58,782)
7	2021	$ (16,110)	$ 6,219	$ (72,298)	$ 7,186	$ (69,110)	$ 7,824	$ (67,068)
8	2022	$ (16,110)	$ 6,374	$ (82,034)	$ 7,545	$ (77,675)	$ 8,333	$ (74,845)
9	2023	$ (16,110)	$ 6,533	$ (91,611)	$ 7,923	$ (85,862)	$ 8,875	$ (82,080)
10	2024	$ (16,110)	$ 6,697	$ (101,024)	$ 8,319	$ (93,653)	$ 9,451	$ (88,739)
11	2025	$ (16,110)	$ 6,864	$ (110,270)	$ 8,735	$ (101,029)	$ 10,066	$ (94,783)
12	2026	$ (16,110)	$ 7,036	$ (119,344)	$ 9,171	$ (107,967)	$ 10,720	$ (100,173)
13	2027	$ (16,110)	$ 7,212	$ (128,242)	$ 9,630	$ (114,448)	$ 11,417	$ (104,866)
14	2028	$ (16,110)	$ 7,392	$ (136,960)	$ 10,111	$ (120,446)	$ 12,159	$ (108,817)
15	2029	$ (16,110)	$ 7,577	$ (145,494)	$ 10,617	$ (125,939)	$ 12,949	$ (111,978)
16	2030	$ (16,110)	$ 7,766	$ (153,837)	$ 11,148	$ (130,901)	$ 13,791	$ (114,297)
17	2031	$ (16,110)	$ 7,960	$ (161,987)	$ 11,705	$ (135,306)	$ 14,687	$ (115,719)
18	2032	$ (16,110)	$ 8,159	$ (169,938)	$ 12,291	$ (139,125)	$ 15,642	$ (116,187)
19	2033	$ (16,110)	$ 8,363	$ (177,684)	$ 12,905	$ (142,330)	**$ 16,659**	$ (115,638)
20	2034	$ (16,110)	$ 8,572	$ (185,222)	$ 13,550	$ (144,890)	$ 17,742	$ (114,007)
21	2035	$ -	**$ 8,787**	$ (176,435)	**$ 14,228**	$ (130,662)	$ 18,895	$ (95,112)
22	2036	$ -	$ 9,006	$ (167,428)	$ 14,939	$ (115,723)	$ 20,123	$ (74,989)
23	2037	$ -	$ 9,232	$ (158,197)	$ 15,686	$ (100,037)	$ 21,431	$ (53,558)
24	2038	$ -	$ 9,462	$ (148,734)	$ 16,470	$ (83,567)	$ 22,824	$ (30,734)
25	2039	$ -	$ 9,699	$ (139,036)	$ 17,294	$ (66,273)	$ 24,308	$ (6,426)
26	2040	$ -	$ 9,941	$ (129,094)	$ 18,159	$ (48,114)	$ 25,888	$ 19,462
27	2041	$ -	$ 10,190	$ (118,904)	$ 19,067	$ (29,047)	$ 27,570	$ 47,032
28	2042	$ -	$ 10,445	$ (108,459)	$ 20,020	$ (9,027)	$ 29,362	$ 76,394
29	2043	$ -	$ 10,706	$ (97,754)	$ 21,021	$ 11,994	$ 31,271	$ 107,665
30	2044	$ -	$ 10,973	$ (86,780)	$ 22,072	$ 34,066	$ 33,304	$ 140,969
31	2045	$ -	$ 11,248	$ (75,532)	$ 23,176	$ 57,241	$ 35,468	$ 176,437
32	2046	$ -	$ 11,529	$ (64,003)	$ 24,334	$ 81,576	$ 37,774	$ 214,211
33	2047	$ -	$ 11,817	$ (52,186)	$ 25,551	$ 107,127	$ 40,229	$ 254,440
34	2048	$ -	$ 12,113	$ (40,073)	$ 26,829	$ 133,955	$ 42,844	$ 297,284
35	2049	$ -	$ 12,415	$ (27,658)	$ 28,170	$ 162,126	$ 45,629	$ 342,913
36	2050	$ -	$ 12,726	$ (14,932)	$ 29,579	$ 191,704	$ 48,595	$ 391,507
37	2051	$ -	$ 13,044	$ (1,888)	$ 31,058	$ 222,762	$ 51,753	$ 443,260
38	2052	$ -	$ 13,370	$ 11,482	$ 32,610	$ 255,372	$ 55,117	$ 498,378

Source: Electric Power Research Institute

The research team used the results of the utility bill savings calculations from the "final VER package" tables and the average annual savings from the "amortized payments" table to determine simple payoff and years-to-positive cash flow, respectively. These results were tabulated to provide the number of years to payback the investment (Table 18).

Table 18: An Example of Payoff Period Employed in Cash Flow Calculation

	Payoff Period, in Years					
	Simple Payoff(2.5% inflation), in yrs	Simple Payoff (2.5% inflation, 2.5% Price Escalation), in yrs	Simple Payoff (2.5% inflation, 4% Price Escalation), in yrs	Amortized Payoff (2.5% inflation, 0% NG price esacalation, 5% APR), in yrs	Amortized Payoff (2.5% inflation, 2.5% NG price esacalation, 5% APR), in yrs	Amortized Payoff (2.5% inflation, 4% NG price esacalation, 5% APR), in yrs
20yr Mortgage	30	23	20	37	28	25
30yr Mortgage				42	31	25

Source: Electric Power Research Institute

Very Efficient Retrofit Package Options for Community Center

This section discusses the development of the initial and final VER package installed in the common area of the project site.

After completing the pilot of the two apartments, the research team performed a similar analysis for the community center by making a baseline model, determining the accuracy of the model, and then designing the VERs package. The savings of the VER package were determined by reviewing the site energy results. Table 19 is an example of the "annual Community Center savings" table.

Table 19: Annual Community Center Savings Calculation with Very Efficient Retrofit Option #2

Beechwood Community Center in CBECC (ducts outside)		Hybrid CBECCC and BEopt	Beechwood Community Center in BEopt v2.3						
	Base Case	Base CC Total (estimated CBECC & BEopt)	ZNE #2 (Common Area)	ZNE #2 (Laundry room, El. dryers)	ZNE #2 (Laundry room, gas dryers)	ZNE #2 Outdoor Lighting (LED)	ZNE Community Center, Total (estimated)	% Savings, estimated	$Saved per year
Spc Heat	679	2,979	-	299	299	-	299	90%	$ 430
Spc Cool	5,027	6,836	3,127	372	372	-	3,499	49%	$ 535
IAQ Vent	94	291	698	164	164	-	862	-196%	$ (92)
Ins Light	1,506	17,500	1,483	264	264	5,220	6,967	60%	$ 1,690
Appl & Cook	759	1,483	847	7,330	645	-	1,492	-1%	$ (1)
Plug Lds	2,694	1,600	1,600	-	-	-	1,600	0%	$ 0
TOTAL	**10,759**	**29,852**	**7,755**	**8,429**	**1,744**	**5,220**	**14,718**	**51%**	**$ 2,427**
% Error	**-71%**	**-19%**							
Spc Heat	772	1,197	649	-	-	-	649	46%	$ 505
Wtr Heat	176	221	63	19	19	-	82	63%	$ 128
Appl & Cook	21	206	19	-	188	-	207	-1%	$ (1)
TOTAL	**969**	**1,538**	**731**	**19**	**207**	**-**	**938**	**39%**	**$ 552**
Annual Savings									**$ 2,980**
$ 0.16	/kWh								
$ 0.92	/Therm								

Source: Electric Power Research Institute

All the cash flow and payoff tables were then incorporated into a final worksheet with the results of the community center VER package. Savings were calculated using gas-savings from occupied apartments and all utility bill savings from the community center in two separate “final tables,” one for the different occupied unit cases along with community center option #1, and another one for community center VER option #2.

The team chose the initial VER Package for the community center using different criteria from that used for the residences and revised the VER package based on experience with the retrofit process of the pilot sites and the other apartments along with internal and external discussions on the EE measures. The initial VER package included:

1. Envelope sealing to 3.0 ACH50 (air change per hour) with aerosol.
2. Sealing, insulating, and protecting the ducts or moving into conditioned space.
3. Possible replacement of the roof-mounted package units.
4. Upgrading the community center-dedicated boiler to a tankless water heater.
5. Conversion to 100 percent LED exterior lighting, including all security lighting.
6. Possible replacement of all clothes washers with ENERGY STAR® rated units.

Beyond the mentioned features, rooftop PV was considered. Installing PV on the rooftop of the community center raises the potential importance of replacing the roof and the possibility of increasing the ceiling insulation, and increases the practicality of bringing the ducts into the conditioned building space. With no PV on the roof, the existing roof could remain and the features listed would be the extent of the package (called “Community Center VER Package #1”). A variant of Package #1 could include increased roof insulation if it is determined that the ducts and the roof are best encapsulated in spray foam. In the case of PV on the roof, the team strongly recommended that the roof be replaced, and as part of the re-roof that the insulation of the roof and ceiling be increased to at least R-20. This package was called “Community Center VER Package #2.”

Final Very Efficient Retrofit Package of the Common Area

The final VER Package of the common area included weatherization improvements, installation of typical and high-efficiency lighting fixtures (that is, LEDs), sealing leakage of ducts and building envelope, and using “free-cooling” by leveraging cool outside air. Reroofing with polyurethane spray-foam and re-ducting was performed by the same process to improve the building’s energy performance, improve performance of ducts ad reduce air infiltration, and the field testing processes and energy monitoring are not repeated in this section. Only the unique field testing plans for the common area are described here.

1. Reroofing using polyurethane spray-foam with an elastomeric coating: The roof and HVAC ducts exposed above the roof of the community center received benefits from reductions in air leakage and improvements in insulation levels. Spray-applied polyurethane foam insulation provided both air sealing and a layer of insulation. This effort focused on the issues that are unique to multifamily applications, specifically how

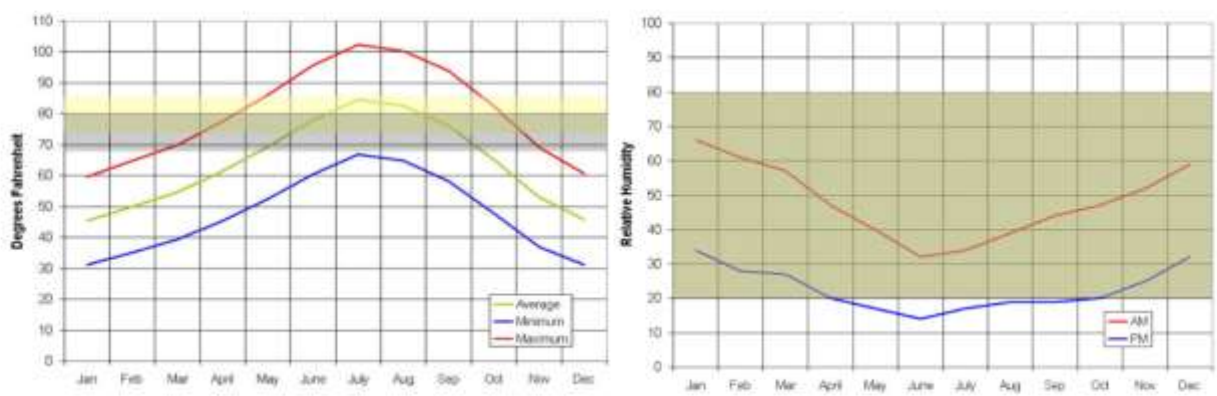
to deal with the possibility of sealant traveling from one apartment to another, or being wasted through large penetrations to piping chases. Two primary objectives were: 1) testing the practical effectiveness of the aerosol-based envelope sealing methodology in the common area of Beechwood Complex; and 2) estimating the first-cost savings and heating/cooling load reductions that may accrue from this type of sealing.

2. Aerosol space-sealing technology: The aerosol space-sealing technology, developed by researchers at the University of California, Davis Western Cooling Efficiency Center (WCEC), had previously been tested to seal leaks in building envelopes, both in laboratory tests and in actual homes in the field. Previous tests had shown a reduction of 50 percent in leakage areas. This project field tested the practical effectiveness of the aerosol-based envelope sealing methodology for the first time in a multifamily building application and estimated the first-cost savings and heating/cooling load reductions to accrue from this type of sealing. The researchers believe there is a potential to further reduce building leakage area. The technology used a compressed nitrogen nozzle to aerosolize the liquid sealant and disperse the aerosol sealant under pressure into the house. The sealant follows small air-streams that form in and around the leaks; however, the mass of the aerosol causes the particles to hit the edges of the leaks, at which point some of the particles will stick to the edge. Over time, a deposit of the aerosol particles builds up in and around the leaks, sealing them. This task focused on the issues that were unique to multifamily applications, specifically how to deal with the possibility of sealant traveling from one apartment to another, or being wasted through large penetrations to piping chases. Two primary objectives in this research of employing aerosol technology: 1) test the practical effectiveness of the aerosol-based envelope sealing methodology in the common area of Beechwood Complex; and 2) estimate the first-cost savings and heating/cooling load reductions that may accrue from this type of sealing.

3. Economizer Upgrade to Utilize Cool Outside Air. The common area of the Village at Beechwood is a residential-sized building but adopts an operational schedule same as an office (for example, 7 a.m. to 6 p.m.). It is equipped with two rooftop units of six tons of refrigeration tonnage (4 ton + 2 ton) to serve two offices for facility managers, laundry room, two restrooms and a space for gathering. Economizers are typically not required for rooftop units (RTUs) that are less than 4.5 tons (that is, economizers on air conditioning units larger than 54,000 British thermal units (Btu)/hr according to California Title 24-2013), so adding the economizing component requires a special order of economizing metal piece and control piece to upgrade the RTUs. Lancaster is located in California climate zone 14, which is characterized by wide swings in temperature between day and night (see the historical weather info of California climate zone 14) (Figure 25). Hot summer days are typically followed by cool nights, thus providing an excellent opportunity to use economizers to night-flush the building and take advantage of early morning cool outside air to provide free cooling. There are four types of economizers in the market: dry bulb, enthalpy, differential enthalpy and integrated differential enthalpy. The dry bulb and enthalpy options adopts only one sensor but the

other two options require two sensors and thus more complicated in configuration and maintenance. As the name states, dry bulb economizer allows low temperature outside air in based on the outside air dry bulb temperature but regardless of the outside air humidity; whereas, enthalpy economizer determines outside air based on humidity. The right type of economizer should be determined by the climate zone and the control needs of the building. Climate zone 14 has hot and dry summers eliminate the needs of worrying too much outside air moisture content being brought into the building. The common area retrofitted is a small sized building and also prefers controls with easier configuration. Thus, dry bulb economizer is the right choice for this building and its climate.

Figure 25: Climate Zone 14 Temperature and Relative Humidity



Source: Electric Power Research Institute

Summary of Very Efficiency Retrofit Package Options

Recommended VER package options for the occupied apartments are summarized in Table 20 through Table 23.

Final VER package tables track spending on utilities and calculate the annual savings of the VERs package. An example of the final VER package table is provided in Table 24 through Table 27.

The initial VER package for the common area is shown in Table 28 through Table 30.

Table 20: Very Efficient Retrofit Package Option 1

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)
Misc Electric Loads	Unmonitored	Home Energy Management System				
Unfinished Attic	Ceiling, 2" cellulose, R-6.4, gr. 3			Re-Roof, 1.25" (R8) membrane, 7" (R22) blown-in		
		Ceiling, R7 batt	Ceiling, R7 batt		Ceiling, R7 batt	Ceiling, R7 batt
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage				
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50				
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Shared 100gal Boiler (0.80 EF)				
	Duplex: 40gal Storage (0.62 EF)				Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)
Hot Water Pipes	Multiplex: Uninsulated, underground	Replaced with new, 2" insulated pipes				
Solar Water Heating	None	Everyday Energy; Evacuated tube drainback				
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head		Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head
Refrigerator	18 cu ft., pre-1999	18 cu ft., new	18 cu ft., new		18 cu ft., new	18 cu ft., new
Lighting	Incadescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting				

Source: Electric Power Research Institute

Table 21: Very Efficient Retrofit Package Option 2

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)
Misc Electric Loads	Unmonitored	Home Energy Management System				
Unfinished Attic	Ceiling, 2" cellulose, R-6.4, gr. 3	Ceiling, R7 batt	Ceiling, R7 batt	Ceiling, R7 batt	Ceiling, R7 batt	Ceiling, R7 batt
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage				
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50				
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Shared 100gal Boiler (0.80 EF)				
	Duplex: 40gal Storage (0.62 EF)				Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)
Hot Water Pipes	Multiplex: Uninsulated, underground	Replaced with new, 2" insulated pipes				
Solar Water Heating	None	Everyday Energy; Evacuated tube drainback				
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head		Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head
Refrigerator	18 cu ft., pre-1999	18 cu ft., new	18 cu ft., new		18 cu ft., new	18 cu ft., new
Lighting	Incadescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting				

Source: Electric Power Research Institute

Table 22: Very Efficient Retrofit Package Option 3

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)
Misc Electric Loads	Unmonitored	Home Energy Management System				
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage				
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50				
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Bank of commerical tankless DHW (0.95EF), with shared backup boiler (0.80 EF) and cirulation pump				
	Duplex: 40gal Storage (0.62 EF)				Gas, Tankless condensing (0.96 EF)	Gas, Tankless condensing (0.96 EF)
Hot Water Pipes	Multiplex: Uninsulated, underground	Replaced with new, 2" insulated pipes				
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head		Sink aerators, 1.5g/min shower head	Sink aerators, 1.5g/min shower head
Refrigerator	18 cu ft., pre-1999	18 cu ft., new	18 cu ft., new		18 cu ft., new	18 cu ft., new
Lighting	Incadescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting				

Source: Electric Power Research Institute

Table 23: Very Efficient Retrofit Package Option 4

Category Name	Beechwood 2 Bed Duplex Base Case	ZNE #1b (Building 1, Units 1 - 8)	ZNE #1 (Building 2, Units 9 - 18)	ZNE #1 (Building 3, Units 19 - 28)	ZNE #1c (Building 20, Units 83 - 84)	ZNE #1c (Building 21, Units 85 - 86)
Misc Electric Loads	Unmonitored	Home Energy Management System				
Ducts	32% Leakage, Uninsulated	R22, sealed to <10% leakage				
Air Leakage	14.1 ACH50	Sealed to 3.0 ACH50				
Water Heater	Multiplex: Shared 100gal Boiler (0.80 EF)	Gas, Tankless condensing (0.96 EF)				
	Duplex: 40gal Storage (0.62 EF)					
Faucets & Shower heads	No aerators, >1.5g/min shower head	Sink aerators, 1.5g/min shower head				
Refrigerator	18 cu ft., pre-1999	18 cu ft., new				
Lighting	Incadescent interior, CFL exterior	CFL interior lighting, CFL exterior lighting				

Source: Electric Power Research Institute

Table 24: Example Cost Effectiveness Determination of Very Efficient Retrofit Package Option 1

Occupied Units VER Package, Option #1	Annual	Gas Usage (Therm, $)			Elec. Usage (kWh, $)		
		Base	VER	Sav.	Base	VER	Sav.
Building 1	Energy	333	114	219	4,543	3,629	915
	Cost	$ 307	$ 105	$ 201	$ 467	$ 373	$ 94
Building 2	Energy	317	131	186	4,646	3,731	915
	Cost	$ 291	$ 120	$ 171	$ 478	$ 384	$ 94
Building 3	Energy	295	99	196	3,894	3,212	682
	Cost	$ 272	$ 91	$ 180	$ 401	$ 330	$ 70
Building 20	Energy	318	185	133	3,887	3,187	699
	Cost	$ 293	$ 170	$ 122	$ 400	$ 328	$ 72
Building 21	Energy	490	299	191	7,202	4,637	2,566
	Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

Source: Electric Power Research Institute

Table 25: Example Cost Effectiveness Determination of Very Efficient Retrofit Package Option 2

Occupied Units VER Package, Option #2	Annual	Gas Usage (Therm, $)			Elec. Usage (kWh, $)		
		Base	VER	Sav.	Base	VER	Sav.
Building 1	Energy	333	114	219	4,543	3,631	912
	Cost	$ 307	$ 105	$ 201	$ 467	$ 373	$ 94
Building 2	Energy	317	131	186	4,646	3,731	915
	Cost	$ 291	$ 120	$ 171	$ 478	$ 384	$ 94
Building 3	Energy	296	103	193	3,894	3,229	665
	Cost	$ 272	$ 94	$ 178	$ 401	$ 332	$ 68
Building 20	Energy	318	185	133	3,887	3,219	667
	Cost	$ 293	$ 170	$ 122	$ 400	$ 331	$ 69
Building 21	Energy	490	299	191	7,202	4,637	2,566
	Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

Source: Electric Power Research Institute

Table 26: Example Cost Effectiveness Determination of Very Efficient Retrofit Package Option 3

Occupied Units VER Package, Option #3	Annual	Gas Usage (Therm, $)			Elec. Usage (kWh, $)		
		Base	VER	Sav.	Base	VER	Sav.
Building 1	Energy	333	168	166	4,543	3,519	1,025
	Cost	$ 307	$ 154	$ 152	$ 467	$ 362	$ 105
Building 2	Energy	327	172	155	4,606	3,581	1,025
	Cost	$ 301	$ 158	$ 143	$ 474	$ 368	$ 105
Building 3	Energy	296	158	137	3,894	3,213	681
	Cost	$ 272	$ 145	$ 126	$ 401	$ 330	$ 70
Building 20	Energy	318	185	133	3,887	3,220	667
	Cost	$ 293	$ 170	$ 122	$ 400	$ 331	$ 69
Building 21	Energy	490	299	191	7,202	4,637	2,566
	Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

Source: Electric Power Research Institute

Table 27: Example Cost Effectiveness Determination of Very Efficient Retrofit Package Option 4

Occupied Units VER Package, Option #4	Annual	Gas Usage (Therm, $)			Elec. Usage (kWh, $)		
		Base	VER	Sav.	Base	VER	Sav.
Building 1	Energy	333	164	169	4,543	3,519	1,025
	Cost	$ 307	$ 151	$ 156	$ 467	$ 362	$ 105
Building 2	Energy	327	168	159	4,646	3,581	1,065
	Cost	$ 301	$ 155	$ 146	$ 478	$ 368	$ 110
Building 3	Energy	296	155	141	3,894	3,213	681
	Cost	$ 272	$ 142	$ 130	$ 401	$ 330	$ 70
Building 20	Energy	318	185	133	3,887	3,220	667
	Cost	$ 293	$ 170	$ 122	$ 400	$ 331	$ 69
Building 21	Energy	490	299	191	7,202	4,637	2,566
	Cost	$ 451	$ 275	$ 175	$ 741	$ 477	$ 264

Source: Electric Power Research Institute

Table 28: Example of Community Center Very Efficient Retrofit Package Option 1

	Common Area and Laundry Room	
Features	Base Case	ZNE #1
Envelope Leakage	7	3
Community Center Air Conditioning	12 SEER	16 SEER AC (2-stage)
Community Center Furnace	80% AFUE	80% AFUE
Laundry Air Conditioning	12 SEER A/C	14 SEER H/P
Domestic Hot Water	100g, 0.8 EF	0.96 EF tankless
Lighting	Compact fluorescent (interior), high intensity discharge (exterior)	LED
Clothes Washer	Standard (EF = 2.47)	ENERGY STAR® (EF = 1.41)

AFUE = annual fuel utilization efficiency; EF = energy factor.

Source: Electric Power Research Institute

Table 29: Example of Community Center Very Efficient Retrofit Package 2

	Features	
	Occupied Units	
	Base Case	**ZNE #1**
Roof	Graveled	R8 Membrane
Refrigerator	Pre-1999	New
Envelope Leakage	7	3
Ducts	Uninsulated, 31% leakage	R22, 10% leakage
DHW	100g, 0.8 EF	0.96 EF tankless
Lighting	CFL (ins.), HID (ext.)	LED
Clothes Washer	Standard (EF = 2.47)	EnergySTAR (EF = 1.41)
MELs	No control	HEM

Source: Electric Power Research Institute

Table 30: Example of Community Center Very Efficient Retrofit Package 3

	Features	
	Common Area + Laundry Room	
	Base Case	**ZNE #1**
Roof	Graveled	R17 ballasted foam
Envelope Leakage	7	3
CC A/C	12 SEER	16 SEER AC (2-stage)
CC Furnace	80% AFUE	80% AFUE
Laundry Furnace	None	14 SEER H/P
DHW	100g, 0.8 EF	0.96 EF tankless
Lighting	CFL (ins.), HID (ext.)	LED
Clothes Washer	Standard (EF = 2.47)	EnergySTAR (EF = 1.41)

Source: Electric Power Research Institute

CHAPTER 4: Emerging Technologies

As part of this project, two tenant apartments were isolated as emerging technology units (Building 11, 3 bedroom units). Though exact definitions vary, emerging technologies are those that are not fully market ready and have undergone limited testing, but which could potentially be near-commercial scale or commercialized in the next three years. For purposes of this project, the research team defined emerging technologies as those technologies that could potentially fit into existing utility emerging technologies programs. Based on these considerations, a Technical Advisory Committee consisting of representatives from both Southern California Edison (SCE) and Southern California Gas identified possible emerging technologies that could be installed in this project either on the common areas or on tenant units.

Most emerging technologies have not made their way into building models. This makes it difficult to include them in packages of energy efficiency retrofits such as the very efficient retrofit analysis described in the previous chapter. As a result, the research team conducted a separate evaluation of these measures using the same data acquisition and analysis methodology. For some technologies that have a considerable amount of pilot testing behind them (such as smart thermostats), the team included an estimated savings in the models based on other field tests. Even if the technologies did not make it into the implementation list, much time was invested into investigating these opportunities and many lessons were learned from each investigation.

Based on the input from the utilities, the research team conducted an analysis of the various technologies evaluated based on the following criteria:

- Fit of technology with the type of construction.
- Maturity level of technology – if perceived risk was high, it might not be a good fit.
- Past research conducted into these technologies.
- Potential for observable energy savings as part of a package of measures.
- Impact to customer from installation process.

Technologies Considered for Emerging Technologies Evaluation

A meeting with all utility partners in March 2015 resulted in the following comprehensive list of possible technologies for consideration:

1. Gas condensing tankless water heater for laundry.

2. High efficiency rooftop unit (RTU) with fault detection and diagnostic and variable speed indoor fans.
3. Foam roof insulation, cool roof and insulated ducts (existing roof removed).
4. Aerosol envelope sealing.
5. Ozone retrofit kits (cold water).
6. Moisture sensing retrofit for dryers.
7. LED bi-level.
8. Weather bug testing.
9. Non-intrusive load monitoring systems.
10. Thermostats with EE and demand response (DR) capability.
11. Solar thermal with evacuated tubes.
12. Boxing and ducts in semi-insulated spaces.
13. Home Energy Management Systems (wireless access).
14. Insulated underground piping.
15. Messaging for behavioral change.
16. Post-installation surveys.
17. Retrofit rooftop unit with economizer control.
18. Navien 99 percent gas tankless water heaters for residential applications.
19. On-demand recirculation for residential.
20. Pilot less range.
21. Shower Start (City Gardens) – customer experience.
22. Mini splits with demand response.
23. Other three heating options – backup wall furnace, condensing gas backup.

Analysis of the Technologies

Table 31 summarizes the analysis of the technologies identified.

Table 31: Analysis of the Technologies

Technology	Fuel	Brief Tech Overview	Disposition
1. Gas Condensing Tankless water heater for laundry	Gas	Reduce water heater usage with tankless	Eliminated from consideration for ozone retrofit
2. High Efficiency RTU w/ fault detection and diagnostic (and variable speed indoor fans)	Both	High SEER, variable speed HVAC units that also perform fault detection for EE	All features not available with the 4 Ton unit on common area (largest unit)
3. Foam roof insulation, cool roof and insulated ducts (existing roof removed)	Both	Insulate roof of common area along with exposed ducts with foam insulation	Statement of work prepared and bidding of work in progress
4. Aerosol Envelope Sealing	Both	Seal leaky wall and envelope with aerosol sealing	Statement of work completed and preparations in progress
5. Ozone retrofit kits (cold water)	Gas	Adding ozone to cold water can clean laundry without hot water	Product selected and being procured for installation in common area
6. Moisture sensing retrofit for dryers	Gas	Sense dryness of clothing and turn off dryer as early as possible	Found a vendor, early stage technology, evaluating for risk to laundry equipment
7. LED bi-level	Electric	Change brightness of external lights	Being considered as part of Building 11 emerging technologies measures
8. Thermostats with EE and DR capability	Electric	Smart communicating thermostats that could reduce energy use	Installed in tenant apartments along with Wi-Fi hotspots. Installed three different technologies including nest, ecobee and Nexia
9. Weather bug testing for Smart Thermostats	Both	Overlay optimization software that uses weather data to reduce HVAC energy use	Working with vendor to gain access to ecobee thermostats through an API so overlay optimization can be applied.
10. Non-intrusive load monitoring systems	Electric	Enables low cost disaggregation of end use loads	Evaluating three technologies from LoadIQ, Chai Energy and Bidgely

Technology	Fuel	Brief Tech Overview	Disposition
11. Solar Thermal with evacuated tubes	Gas	Evacuated tube solar collector	Installed for apartments
12. Boxing and ducts in semi-insulated spaces	Both	Reduce duct leakage and get ducts into conditioned spaces	Completed for all tenant units
13. Home Energy Management Systems (wireless access)	Both	Enable centralized management of energy use	Eliminated from consideration due to complicated technology not amenable to customer adoption
14. Insulated underground piping	Gas	Insulate piping from central water heating system	Completed as part of tenant measures
15. Messaging for behavioral change	Both	Provide in-home devices that provide feedback	Replaced for consideration by non-intrusive load monitoring (NILMs) devices
16. Post-installation surveys	Both	Survey to understand impacts	To be conducted
17. Retrofit Rooftop unit with economizer control and fresh air ventilation	Both	Weather in Lancaster has extremes. Substantial energy savings possible through economizer	Seeking suppliers. Difficult to find products that can retrofit to small commercial units
18. Navien 99% gas tankless water heaters for residential applications	Gas	Highest efficiency gas tankless water heater	Procured and will be installed in Building 11 tenant unit
19. On-demand recirculation for residential	Gas	Considered for reducing energy use with central water heating system	Included as part of piping upgrades for centralized water heating
20. Pilot less range	Gas	Reduce cooking gas use	Requires new appliances and not possible within budget
21. New Refrigerator	Electric	Reduce electricity use	ENERGY STAR® appliances not viable within budget. SCE program requires out-of-pocket for tenants, but project cannot pay tenants.
21. Shower Start	Gas	Reduce water use when waiting for hot water	Evaluated by LINC in other properties and not found very effective
22. Mini splits w/ DR	Electric	Eliminate duct losses through ductless systems	Not implemented due to fuel switching concerns, which is not allowed in

Technology	Fuel	Brief Tech Overview	Disposition
			EE programs in Southern California.
23. Ductless heat pumps with gas backup	Both	European unit – Daikin Altherma, that provides combined space and water heating with condensing boiler	Trying to procure from Belgium, still difficult to get. Dealer says not qualified under Title 24
24. Wall furnaces	Gas	Option for more efficiency ductless heating	Gas lines not available inside tenant units and not viable

Source: Electric Power Research Institute

Technology Implementation

Based on the technology analysis, many technologies were not included in the retrofit due to cost or availability issues. However, the researchers believe these technologies would be good candidates for evaluation through other earlier stage technology demonstrations funded by the Energy Commission or by the utilities' emerging technologies programs. The following summarizes the decision and rationale for each measure:

- Envelope aeroseal sealing: This is a technology in development by the Western Cooling Efficiency Center. At the time of the project launch, it had been tested in other homes and had very limited implementation, but there was huge potential to the technology in addressing cost effective envelope sealing. However, because it could be disruptive to tenants it was only implemented in the common area.
- Smart thermostats: Program adoption of smart thermostats advanced considerably in during the project and were implemented. However, lack of reliable Wi-Fi in low-income housing became a barrier.
- Moisture sensing dryer retrofit kit: This gas-savings technology had good potential but concerns regarding warranty and customer perception (low run times for the same cost) meant that this technology could not be tested in this project. It could have substantial benefit when applied in new dryers by manufacturers.
- Ozone purification system: This was also a very interesting gas-savings technology. However, when the water heating for the laundry was monitored, it was found that the heater was non-operational so there would be no savings from implementing this technology.
- Katalyst variable speed controls upgrade: This technology was studied for potential to upgrade single-speed air conditioning systems to variable speed. However, the size and cost of the air conditioning units including the common area apartments proved to be a barrier.

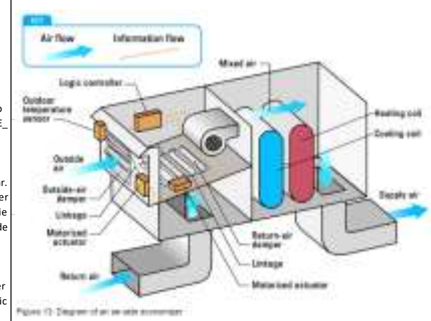
- Belimo zip economizer: This was a lower cost retrofit that was implemented. The zip economizer incorporated an enthalpy optimization based on zip code that showed substantial potential.
- Ilios engine driven heat pump: This was a very interesting gas energy generation and efficiency technology. However, the system was too large for the apartments and after reviewing the research this technology was not implemented.
- Ductless mini splits with gas heating: From this research and implementation, the team supports ductless mini splits as an effective retrofit option for existing buildings. They offer the following benefits:
    - Eliminate duct losses, both from thermal transport and leakage.
    - Avoid opening walls and insulation and resultant contaminant issues.
    - Provide variable speed operation for more cost effective and local cooling.
    - Compatibility with smart thermostats that increase customer satisfaction.

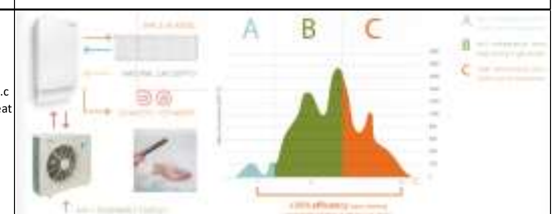
  However, the option to keep gas heating for customer economics with ductless mini-splits is necessary. A ductless mini-split with condensing gas backup is available through Daikin in Europe (Belgium, France, and so on). Despite major effort, the team was unable to import and install it in this project, due to servicing and availability issues. The gas backup also avoids possible issues with electric distribution systems due to electric heat elements in heat pumps, and eliminates the need to run additional electrical lines. More investment in evaluating this technology is encouraged.

Detailed Analysis and Specifications of Emerging Technologies

The individual technologies considered by the team are in Table 32.

Table 32: Specifications of the Emerging Technologies Considered by Team

ET Measures		Tech Description	Pros	Cons	Barriers to test	Website	Figure
Rooftop unit with economizer control	**Dry Bulb Economizer**	When there is a call for cooling, a temperature sensor determines if outside air is at or below a certain temperature setpoint (e.g., 55 F), the outside air damper is controlled allowing more outside air coming in to be mixed with return air to provide cooling.	1. Demand control ventilation to provide fresh air when CO_2 is high 2. Electric energy saving by cooling with outside air thus reduce mechanical cooling	Outside air may be low enough in temperature but may be too humid for occupant comfort.		**Tech Description**: [1]. Steven T. Taylor, Hwakong Cheng. Economizer High Limit Controls and Why Ehthalpy Economizers Don't Work. "http://www.cmfnh.com/documents/ASHRAE_Journal_QA.pdf". November 2010 [2]. Airside Economizer. http://www.energystar.gov/index.cfm?c=power_mgt.datacenter_efficiency_economizer_airside . **Product Example**: [Carrier] http://dms.hvacpartners.com/docs/1009/public/0c/48-50h-t-2t.pdf	
	Enthalpy Economizer	Similar to the dry bulb economizer, the ehthalpy economizer requires a temperature sensor and a relative humidity sensor to calculate the outside air enthalpy. Then the outside air enthalpy is compared with a setpoint	1. Demand control ventilation to provide fresh air when CO2 is high 2. Electric energy saving by cooling with outside air thus reduce mechanical cooling	If the coil is dry, this method can bring large error and also impacts energy consumption. If the coil is humid, this method is fine.			
	Differential Enthalpy Economizer	These use two sensors. One measures the return air enthalpy, while the other measures outdoor air enthalpy. Dampers are modulated for optimum and lowest enthalpy to be used for cooling.	1. Demand control ventilation to provide fresh air when CO2 is high 2. Electric energy saving by cooling with outside air thus reduce mechanical cooling	1. It requires four sensors and thus the most expensive and the most prone to sensor error. 2. It is not the most high efficient method, not even in theoretical			
	Catalyst	It is a complete HVAC energy efficiency upgrade that includes several new components, adds 5-6 new sensors and an easy-to-install pre-wired kit	1. Converts CAV to VAV and reduces fan energy use and integrates economizer controls 2. An easy/fast to install product			http://transformativewave.com/Contents/Item/Display/33 **Brochure**: [1] http://transformativewave.com/Media/Default/docs/CATALYSTlite-Product-Brochure.pdf [2] http://transformativewave.com/Media/Default/docs/CATALYST-Product-Brochure.pdf	
Navien 99% gas tankless water heaters (Navien NPE -Standard)		Gas tankless water heaters use high-powered burners to quickly heat water as it runs through a heat exchanger	1. Saves standby energy for keeping water warm in the tank 2. Higher energy efficiency	1. Some complaints about customer service are found online 2. Higher initial cost on equipment and potentially wiring/plumbing 3. Capability of simultaneous tasks and potential temperature swing. 4. More readings are available at: http://www.waterheaterrescue.com/pages/WHRpages/English/Longevity/tankless-water-heaters.html	1. Hard to verify the cost effectiveness. 2. Warranty of product is hard to test	**Product**: http://us.navien.com/__DATA/ProductDocument/2014/12/8/[1]_Navien%20NPE-A-S%20Brochure%2014-1205.pdf	
On-demand hot water recirculation		Recirculates the ambient temperature water in the hot water lines (water that is normally lost down the drain) back to the water heater. This way it saves hot water.	1. Up to 80% faster in heating water than just letting the water run down the drain [data referred to product website] 2.The water savings comes from the fact that you no longer have to run water down the drain waiting for hot water. 3. The energy savings comes from the reduction in water running down the drain that then has to be treated for sewage.	1. C3-100 does not provide installation kit but c3-100PF product should include all installation kit [comment referrred to Amazon customer review].	Hard to establish a water usage baseline overtime to quantify the actual savings.	**Product**: D'MAND Kontrol® Systems: http://www.gothotwater.com/hot-water-systems/how-it-works	
Pilotless Ignition Gas Range		With the spark ignitor system, electricity simply sparks when control is turned to the LITE position. Gas is simultaneously released and ignites when it comes in contact with the spark.	1. Pilotless ignition saves energy by eliminating lighting the burner. 2. Saves energy by around 30% less gas than typicl pilot range uses. Since no standling pilot light, no gas is used unless it is needed. [Data referrred to geappliance.com] 3. The cooktop surface is cool to touch when not in use because there is no pilot light burning continuously		Hard to establish a baseline to quantify the energy savings. Because using gas burners is customer behavior related and is hard to find an exact baseline	**Tech Description**: http://www.geappliances.com/search/fast/infobase/10000751.htm. **Product**:	

ET Measures		Tech Description	Pros	Cons	Barriers to test	Website	Figure
Shower Start		The thermostatic shut-off valve allows the shower to save the hot water when it becomes warm for the people (behavioral waste)	1. Eliminate behavior waste by saving water and energy during shower warm-up. 2. Does not interfere showerhead's feel or flow. 3. Compatible with virtually all showerheads and shower arms (1/2" NPT fittings) 4. In california, 10%	Refer to customer reviews on Amazon. Negative comments mostly come from : 1. Reliability 2. Customer service [comment referrred to Amazon customer review]	Hard to establish a baseline to quantify the energy savings. Because taking shower is customer behavior related and is hard to find an exact baseline	**Tech Description**: http://thinkevolve.com/shop/showerstart-tsv/ **Product**:	
Aerosol Envelope Sealing		Aeroseal is a system that uses an aerosol-based sealant mist to seal the leaks in ductwork	The technology works fast, doesn't require a contractor to crawl through attics or punch holes in walls and the simple payback can be in less than two years	N/A		**Tech Description**: http://wcec.ucdavis.edu/aerosol-building-envelope-sealing-demonstration/ **Product**:	
Moisture sensing retrofit for dryers	**SAMSUNG Electric Dryer**	Samsung 7.4 Cu. Ft. Steam Electric Dryer	Moisture sensor is already included and heavy duty of 7.4 cu. Ft.	Need to replace existing dryer		http://www.hhgregg.com/samsung-7-4-cu-ft-steam-electric-dryer/item/DV48H7400EW?cid=PLA-11906630-218918&mr:referralID=1ca614c8-ff17-11e4-8fa7-001b2166c62d	
	Moisture sensor upgrade	Stop the dryer (or send a signal to user) when the clothes are dry by a retrofit with relative humidity sensor	1. Energy saving 2. Protect clothes being overheated	N/A	N/A	**Tech Description**: http://hackaday.com/2014/05/28/a-smart-clothes-dryer/ **Product**:	
LED bi-level		Bi-level fixture controls present an opportunity to save energy by dimming light levels when areas are unoccupied. Bi-level lighting controls can also turn off perimeter light fixtures for much of the day in areas that receive sufficient daylight to meet lighting needs.	Energy saving from LED is significant. Imeplemeting bi-level will further improve the energy savings.	LED itself is already energy efficient; adding an additional LED bi-level control may extend the payback period of the lighting upgrade package.	Hard to differentiate/quantify the energy saving % from the LED or from the bi-level control	**Product**: Bi-Level Luminaire -- Maximize Energy Savings with Controlled Light Levels. http://www.columbialighting.com/content/products/literature/literature_files/co1042.pdf	
Daikin Altherma		Daikin Altherma: The split has an outside unit and an inside unit. The outdoor unit absorbs heat from the outside air and raises it to a temperature high enough to supply heating for the house. This thermal energy then warms the Altherma hot water tank, which in turn supplies hot water for general household use and also the hot water that flows through the household heating system.	1. Depending on the outdoor temperature, the Altherma heat pump chooses between heat pump and gas boil to supply both domestic hot water and heating load 2. Can be integrated with existing radiator and pump work thus an easy/cheaper energy efficiency option.		Needs people that have experience to install properly	**Tech Description**: http://www.daikinme.com/minisite/hybridheatpump/Advantages/ **Product**:	
Messaging for behavioral change		New behavior changes (e.g., new tenants) can impact baseline. An updated message can help on an up-to-date baseline to quantify the energy savings	Integrates occupants behavior into the energy use optimization, which can be very helpful for residential homes.	It requires occupants to engage in behavior change. It can be hard for some people	For low-income homes, behavior energy use waste may only take a small percentage. So it is hard to identify the impact of behavior changes		
Post-installation surveys		Take surveys after ET installations to assist measurement & verification	Easy to implement and gets feedback from occupants	The design of questionaire plays an important role in the success	The survey maybe biased based on the group of people selected		

Source: Electric Power Research Institute

CHAPTER 5: Data Acquisition and Monitoring

The data acquisition and monitoring portion of this project required a site-specific strategy that collected data from multiple sources into a “data warehouse” to support analytics. The Beechwood Complex had 100 apartments, as shown in Figure 26.

Figure 26: Data Monitoring Plan for Village at Beechwood

Source: Electric Power Research Institute

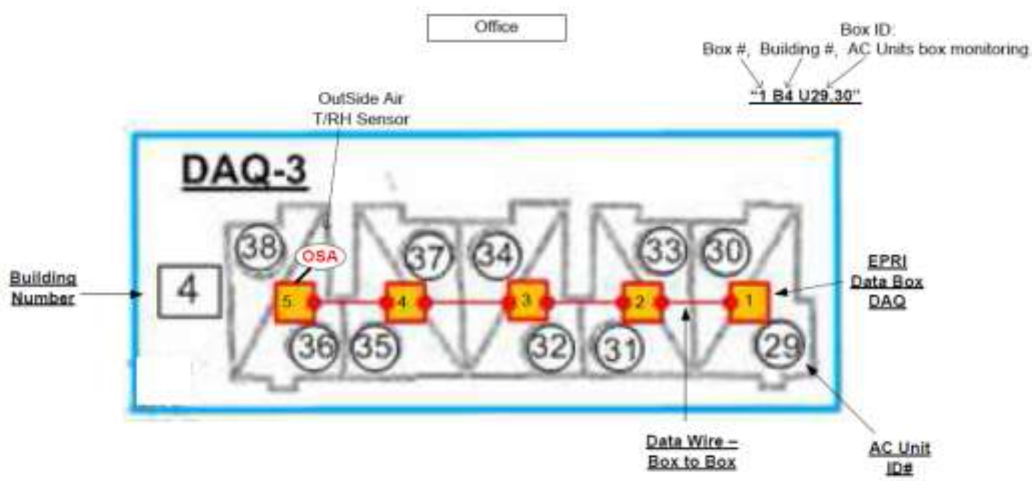
The buildings outlined in red were the 32 test-case apartments for data monitoring, and the buildings outlined in blue were the 14 apartments to be monitored as baseline and the common area. The data acquisition plan consisted of systems to collect and deposit data which was then analyzed by the research team. The systems included: 1) Electric Power Research Institute (EPRI) data acquisition system; 2) non-intrusive load monitoring system for building-wide electric load monitoring; 3) datasheets of field tests; 4) natural gas use data from Southern California Gas Company; 5) solar PV data; 6) smart thermostat data; and 7) electric consumption and billing data on WegoWise. The systems are discussed in more detail below.

Data Acquisition System

The team installed the EPRI data acquisition system in 46 apartments and required 23 data monitoring boxes since each system monitors two apartments. The 46 apartments included all 28 apartments in Buildings 1, 2 and 3; Building 4 monitored as a control unit; and Buildings 14, 19, 20, and 21. Referring to Figure 26, data acquisition (DAQ) 1, DAQ-2, DAQ-3, and DAQ-4 were data-acquisition sub-systems that gathered data from the apartments and transmitted the data to EPRI's database. The solid line connections shown in the figure were dry contacts (hard-wired connections), and dashed lines were representative of wireless data transmission. The data was collected at 1-minute intervals, but the EPRI data server could process for longer intervals of data (such as every 15 minutes) if required. In each apartment, two types of information were collected on site to evaluate comfort and energy performance of the apartments: thermal data (temperature and relative humidity) and power data (voltage and current).

Figure 27 shows the data-acquisition system of Building 4 as an example. The building number was labeled in a square next to the building complex. With the naming rules in mind, Figure 27 shows the Modbus wire connections (RS-485) of DAQ-3 for Building 4. The layout of the Modbus connections also applies for DAQ-1, DAQ-2, and DAQ-4. Thermistors were located in the duct systems to sense the temperature of supply air, return air, and exhaust air. One outside air senor was located at apartment 36 to measure both temperature and relativity humidity. Thus, the differences between inside and outside temperatures of the apartments could be identified to calculate the cooling load. Clamp-on current transformers (CTs) and voltage meters were employed for the measurements to calculate energy consumption. The detailed wire connections of DAQ-3 system are available in drawings in the next section.

Figure 27: Data Acquisition Naming Rules



Source: Electric Power Research Institute

The air conditioning (AC) units were labeled with the apartment's number, and each duplex had two rooftop AC units, as shown in Figure 28. In addition, the data-collection box was also assigned with a number (in yellow background with red border). Thus, a box ID of "1 B4 U29, 30" represents the data collection of collection box #1 (located in building complex 4) from apartments 29 and 30 (the duplex on the right in Figure 29).

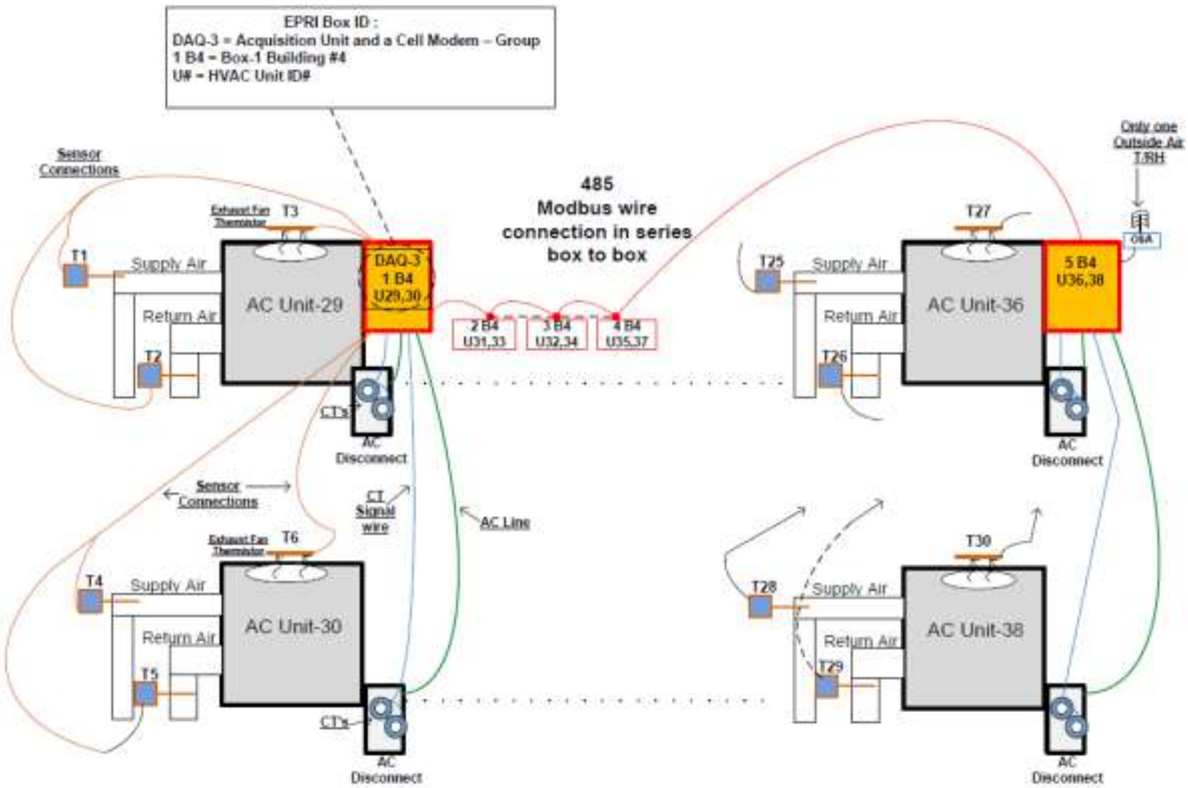
Figure 28: Air Conditioning Units on a Duplex Unit

Source: Electric Power Research Institute

Figure 29 illustrates the data acquisition system setup of the Beechwood Complex. This system monitored 32 test-case apartments (outlined in red) and 14 baseline apartments (outlined in blue). EPRI had a group of dedicated technical staff to ensure reliable operation of the database, and the data acquisition plan was scalable depending on the size of the community and the data points must be monitored.

The data acquisition box is shown in Figure 30 in greater detail. The AcquiSuite Data acquisition block was the "brain" of the data acquisition system, which allowed the team to program the data sampling time and the desired format of data. The AcquiSuite block is constantly polled data at the programmed rate from the Flex IO module and the Power Transducer module. These two modules were connected with the temperature/relative humidity sensors and the CTs, respectively, and made the data available for the AcquiSuite to poll. Each data acquisition box was standalone, hosted its own cell modem and power supply, and protected with a National Electrical Manufacturers Association box for durability.

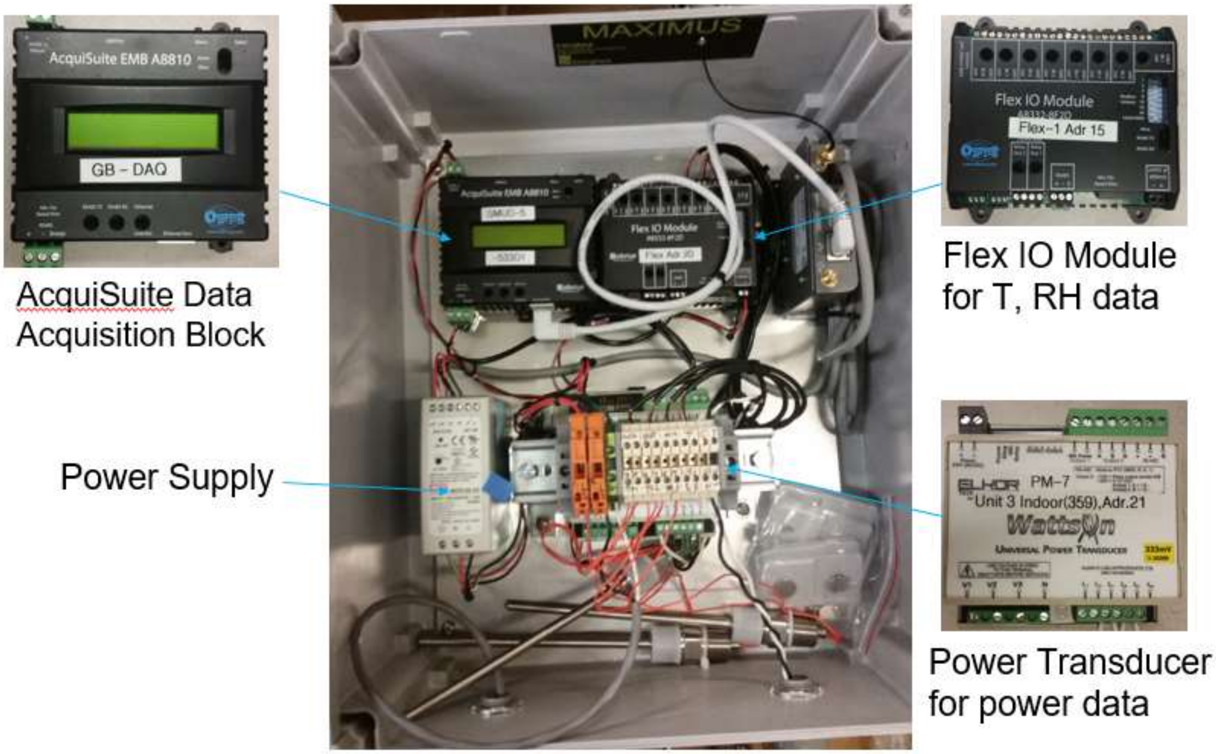
Figure 29: Individual Data Acquisition Units Layout



Source: Electric Power Research Institute

As mentioned earlier, the data acquisition boxes covered 30 apartments and the common area as the treatment group, plus the 10 apartments as the control group. Figure 31 illustrates the data acquisition systems that gathered data from the apartments and transmit the data to EPRI's database. The solid line connections shown in the figure are dry contacts (hard-wired connections), and dashed lines represent wireless data transmission. The electrical data of rooftop units (voltage, current and real power), the outside air conditions (temperature and relative humidity), temperature readings in the ducts (supply air, return air and exhaust air of each apartments) and the flow rates and temperature readings of the solar thermal system were recorded in the EPRI database and were made ready for download.

Figure 30: Utility-Grade Data Acquisition Box



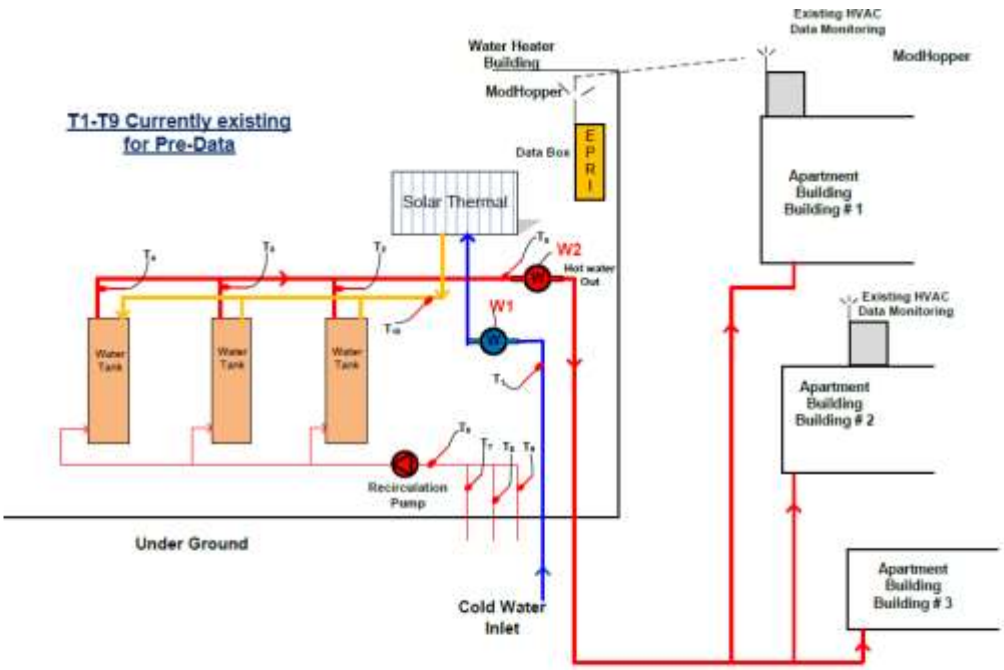
Source: Electric Power Research Institute

Figure 31: Overview of Data Acquisition System Layout

Source: Electric Power Research Institute

In addition, the solar thermal system installed in summer 2015 effectively reduced the use of gas heaters for the hot water needs in Buildings 1, 2 and 3. The monitoring system was established to measure the inlet water temperature T1 (Figure 32), inlet water volume flow rate W1 and outlet temperature T10 to calculate the heat transfer rate of the solar thermal system. The temperature readings of water recirculation and the temperature outlet of tanks allowed the calculation of heat loss rate of the tanks. The monitoring plan allowed us to calculate the overall energy efficiency of the solar thermal system. The solar thermal system reduced natural gas use for the retrofitted apartments and improved overall efficiency considerably.

Figure 32: Hot Water Monitoring System Setup



Source: Electric Power Research Institute

The hot water flow between solar panel and water tank was measured by Amatis flow meters (Figure 33), which were installed by Everyday Energy, monitored both solar thermal and solar PV data.

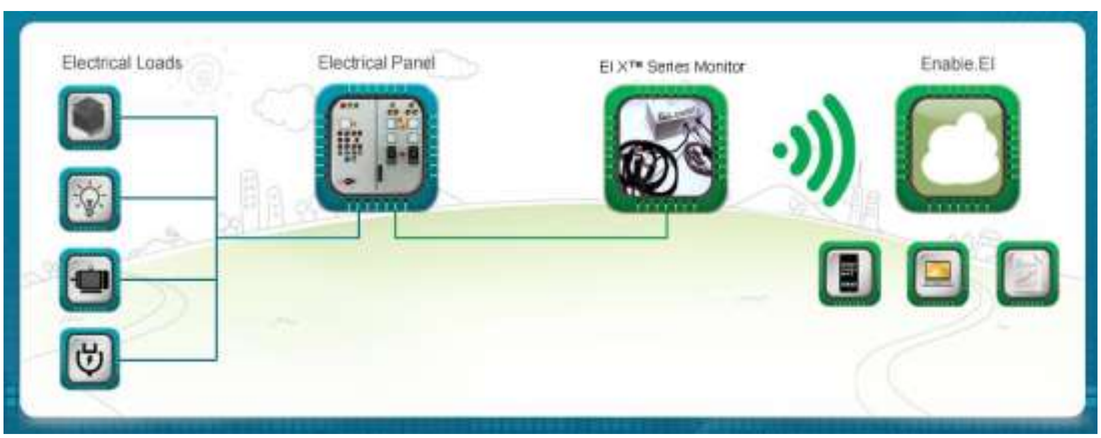
Figure 33: Water Flow Meter Data Collected at Community Water Heating System

Source: Electric Power Research Institute

Non-Intrusive Load Monitoring

In addition to the EPRI data acquisition system, the team installed non-intrusive load monitoring (NILM) technology on Building 1 (covering apartments 1-8) for proof of concept (Figure 34).

Figure 34: Non-Intrusive Load Monitoring System Topology



Source: Electric Power Research Institute

The system installed to collect whole-apartment level data was the first time such a system was used to collect data in a multifamily community. NILM analyzes voltage and current signals to identify end-use devices as they operate. Some of these technologies can drill down to the level of identifying individual appliances, which provides better understanding of plug load usage. The team has previously conducted extensive surveys as well as lab evaluation of these technologies. The research team employed LoadIQ's NILM system installed at the facility's main electrical distribution panel using high-frequency sampling sensors and used relevant algorithms to analyze the home's energy use. The LoadIQ's EI. X series is a cloud-based platform using software to identify and track energy consumption and power quality for specific loads. The total load was disaggregated for specific load's energy use, such as for lighting, plug and HVAC loads. As the sensors were located on the main electrical panel, this equipment was not intrusive to the homes/buildings. LoadIQ installed two EI.4 units at the center panel for each bank of four utility meters. Each EI.4 had four measurement "lines". Each line measured a single apartment, featuring two current transformers rated for measuring each phase (A/B) downstream of each utility meter. The data collected on loadIQ NILM system is shown in Figure 35.

Figure 35: Non-Intrusive Load Monitoring System Collected Data on Building 1

Source: Electric Power Research Institute

The NILM measurement apparatus consisted of the following components:

1. Current measurement: The electrician conducted conduit knockouts from the center panel to the lower left and right circuit breakers. The knockouts enabled the EI.4 CAT5 cables to be fed from the center panels to the respective wires downstream of the meter.
2. Voltage measurement: A brief disruption of electrical service was required at two apartments--one on each bank of four meters--to install voltage sensors on each phase (A/B). Alternatively, piercing voltage connectors could be used without powering off the circuit breakers. The voltage sensor powers the EI.4's.
3. Wi-Fi. The project provided Wi-Fi--via premise-based router or hotspot--for LoadIQ to access and maintain a VPN (virtual private network) connection to each EI.4.
4. Data-sharing: LoadIQ managed a VPN connection to the EI.4 units and shared the login to EPRI to view the data in graphs and download the data.

Figure 36 shows the installation of NILM system. The NILM system was installed on Building 1 (8-plex) and was monitoring apartments 1-8 until the hotspot lost its connection. The NILM system collected data through CTs to monitor the total energy use of the residences and disaggregates to individual loads types. The metered data was uploaded to LoadIQ's cloud through wireless internet connection, in this case using a hotspot located in the case with LoadIQ's EI.X.

Figure 36: Retrofit process of Non-Intrusive Load Monitoring System

Source: Electric Power Research Institute

Field Tests

The project incorporated many energy efficiency measures, including standard weatherization improvements, installation of typical, high-efficiency equipment/measures, and novel approaches to increase the efficiency of the multifamily dwelling units. The novel aspects had been tested and verified to improve of the efficiency the HVAC distribution system by replacing the existing supply ducts with new, R-8 flex-ducts, by making proper connections such that leakage of the new ducts and their connections is near zero. After the supply ducts had been replaced, the entire duct system was buried in insulation to further increase duct-system efficiency. During the process of improving the duct-system efficiency, it was possible to install some roof insulation. After the old ducts had been removed and before the new ducts were installed, loose-fill fiberglass insulation was blown into the attic bays, reaching as far into the bay as possible with the blown-in insulation. To reduce air leakage to/from each dwelling unit, air leakage paths from the duct chase were sealed off. This was achieved while the duct chase was open and ducts were not present. All areas surrounding the duct chase and accessible from the chase that provide an air-path from the chase to other parts of the building (for example the interstitial space in the building consisting of open areas in the walls, and other spaces internal to the building but not part of the living area) were sealed using air impermeable materials and caulk. This reduced air leakage through the building envelope.

The team conducted envelope leakage ("blower door) test and "Duct Blaster" test to measure leakage and evaluate the improvement of thermal performance of the apartments, and identify the impacts on the energy bills and occupant thermal comfort. The “Duct Blaster” test was to measure duct leakage by pressurizing ducts to 25 Pascals (Pa). This involved recording the cubic feet per minute (CFM) needed to achieve a stable 25 Pa with the pressure-fan (“duct blaster”) sealed to the return, and all supply ducts sealed with tape. Painters’ blue masking tape was used for attaching equipment (for example, Duct Blaster) to the apartment or to seal any registers, windows or doors. The envelope leakage (“blower door”) tests were conducted on the apartment with all windows and doors closed (except the front door, where the blower door equipment & fan were installed). The apartment was tested at 50 Pa and the CFM needed to reach 50 Pa reported; if 50 Pa could not be achieved, the actual pressure was noted on the datasheet.

The team conducted envelope sealing after the envelope leakage (“blower door) test and “Duct Blaster” test. The following three steps were conducted for that purpose:

1) While the envelope was depressurized, the blower-door was used to identify major leaks using smoke pencil or other techniques.

2) Sealed detected leaks and/or installed new weather-stripping in typical places; this included weather-stripping and/or sealing around entry door, sliding door, windows, and exterior floor and ceiling joints.

3) After sealing was deemed completed, tested actual leakage with blower-door test. Target leakage was 3.0 ACH50., which is, for 1, 2, and 3 bedroom apartments, 233, 295, and 407 CFM50, respectively. If envelope leakage was higher than the target value, attempt was made to find and seal additional leaks to reduce leakage to or below the target. This ensured that the final CFM50 measured values were equal to or less than the targets specified.

4) Sealed rooftop supply and return duct segments: The “L” ducts between the rooftop package units and the roof / roof penetrations had to be sealed and painted. To further seal leaks and cover existing mastic, light-colored UL-181 approved duct mastic was applied to all accessible connections in these duct segments between the rooftop package units and the roof. After the mastic has cured, both duct segments were covered with white, reflective roof paint.

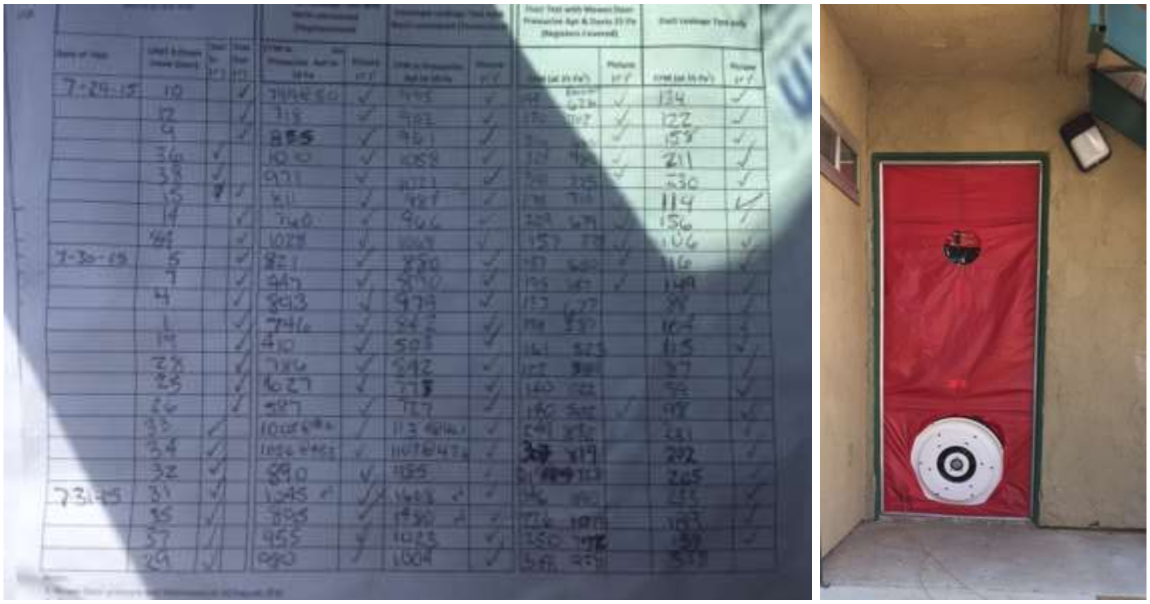
5) Replaced the ducts as necessary and the replaced or retrofitted ducts to be no more than 80 cfm at 25 Pa leakage level (target was 10 percent of unit nominal airflow; that is for 400 cfm/ton x 2ton = 800cfm; 10 percent = 80 cfm).

6) Installed exhaust duct from range hood.

7) Restored ceiling.

After the above were completed, the team conducted duct leakage and envelope leakage tests and the results were recorded in testing sheet, as shown in Figure 37 as an example.

Figure 37: Blower Door Testing Sheet Data of the Final Commissioning



Source: Electric Power Research Institute

Natural Gas Use Data from Southern California Gas Company

The natural gas use of the rooftop units (RTU) for space heating was monitored at a selective level of the apartments. Data was selected from eight apartments from the retrofitted group (30 units) and 14 apartments from the baseline (70 units) to monitor the gas use because of the cost of adding monitoring systems. Southern California Gas Company provided the updates of data on a monthly basis (Table 33). The natural gas data of RTUs were analyzed along with the electric use of ventilation loads of the apartments during the heating season (Table 34).

Table 33: List of Monitoring Points for Gas Use

Appliance	Number	Sizing to monitor
RTU units	20	40,000 Btu
Water heater closet – 3 water heaters 100-gallons each between 200k-270k Btu	2	~750,000 Btu each
Duplex water heaters – 50-gallons each	5	50,000 Btu
Laundry – water heater	1	270,000 Btu
Laundry – dryers aggregate of 5 dryers @25,000 Btu/h	1	125,000 Btu
Cooking – not sure of sizing (if possible)	10	~ 40,000 Btu

Source: Electric Power Research Institute

Table 34: Gas Use Monitored Point

Meter Label #	Monitored Point
1	Unit 7 RTU
2	Unit 6 RTU
3	Unit 9 RTU
4	Unit 13 RTU
5	Unit 18 RTU
6	Unit 19 RTU
7	Unit 25 RTU
8	Unit 26 RTU
9	Unit 29 RTU
10	Unit 37 RTU
11	Unit 35 RTU
12	Unit 43 RTU
13	Unit 44 RTU
14	Unit 45 RTU
15	Unit 71 RTU
16	Unit 72 RTU
17	Unit 71/72 water heater
18	Unit 81 RTU
19	Unit 82 RTU
20	Unit 81/82 water heater
21	Unit 85 RTU
22	Unit 86 RTU
23	Unit 85/86 water heater
24	Unit 97 RTU
25	Unit 98 RTU
26	Unit 98/97 water heater
27	Laundry Room water heater
28	Common Area RTU
29	Common Area RTU
30	Bld 20 Tankless water heater
36	Unit 71/72 Duplex Total Usage
37	Water Heater Closet, 1 water heater
38	Water Heater Closet, 2 water heaters
39	Unit 81/82 Duplex Total Usage
40	Unit 85/86 Duplex Total Usage
41	Unit 98/97 Duplex Total Usage
42	Laundry Room 10 dryers

Source: Electric Power Research Institute

Solar Photovoltaic Data

The multifamily rooftops can be a valuable real estate space and add extra value by providing electricity from renewables such as PV. Beechwood, like many communities, provides rooftop for mounting PV and solar thermal system not only on the apartments but also on the parking structures. This project retrofitted 30 apartments and thus the PV system was sized to cover the 30 apartments towards zero-net energy; however, the system is connected to provide electricity for the entire community. The research team conducted data analysis for this community solar system as if they were installed for individual units (for the 30 apartments) for ZNE. Figure 38 shows portions of the PV system and the corresponding monitoring interface.

Figure 38: Solar Photoltaic System and the Data Monitoring System User Interface

Source: Electric Power Research Institute

Home Energy Management System Smart Thermostat Data

The home energy management system (HEMS) ecosystem allowed control of many points from the interface of the thermostats, such as lighting, security and blinds control. This project only focused on climate control, but the controls could be expanded to other end uses, as the major home automation product providers offered networked controls that covered HVAC, lighting and plug loads; these controls could be provided from the aggregation platform through user-friendly user interface. Smart thermostats were installed in 30 apartments, and allowed users to set climate control schedules on the user interface directly, or remotely from their smart phones or computers. Ecobee, Trane Nexia, and Nest Thermostats were installed in the apartments (10 of each brand) (Table 35).

Table 35: Smart Thermostat Brands and Installed Apartment Unit Number

Ecobee	Trane Nexia	Nest
Building1 Unit03	Building1 Unit1	Building1 Unit02
Building1 Unit04	Building1 Unit05	Building1 Unit08
Building1 Unit07	Building1 Unit06	Building2 Unit11
Building2 Unit10	Building2 Unit09	Building2 Unit12
Building2 Unit13	Building2 Unit15	Building2 Unit14
Building2 Unit17	Building2 Unit16	Building2 Unit18
Building3 Unit21	Building3 Unit20	Building3 Unit19
Building3 Unit22	Building3 Unit24	Building3 Unit23
Building3 Unit26	Building3 Unit25	Building3 Unit27
Building20 Unit84	Building3 Unit28	Building20 Unit83

Source: Electric Power Research Institute

The project found that some of the occupants enjoyed the easy-to-use features as provided by smart thermostats, and their feedback has been positive on the effectiveness of comfort improvement. However, it was also found that a reliable internet connection was an issue here since most occupants did not have Wi-Fi connection. The project provided hotspots, but only a third of those hotspots remained functional after three months of installation. In 2016, the settings of the thermostats had to be reinitialized but could not be fully brought back online. This problem was the result of high tenant changeover rate at The Village at Beechwood during which hotspots were unplugged frequently for various reasons, cutting off the connection established with the smart thermostats. The only thermostat still connected is the one in the common area, where the Wi-Fi is professionally maintained for business purposes.

Electricity Usage and Billing Data

LINC Housing, LLC uploaded all the electricity use data onto WegoWise website (Figure 39). However, the data that could be released to LINC, and consequently the team was limited by the apartments that have the customer agreement with SCE to share the data. Given the turnover rate was high, the individual apartment’s energy usage and bill data were not significant enough to study occupant behavior and preferences.

Figure 39: WegoWise Page for Downloading Data

Source: WegoWise

CHAPTER 6: Procurement, Installation, Commissioning, and Occupant Education

Very Efficient Retrofit Package Procurement

This chapter describes the equipment and materials details for the very efficient retrofit (VER) package, including budgeted, expected and the actual costs incurred, and provides information regarding VER components and packages and analysis from cost comparisons. The final VER packages were defined as Home Energy Management System (HEMS), Cool Roof, Air Leakage/Ducts, Refrigerators, Lighting, Photovoltaic (PV) System, Solar Hot Water, and Insulated Hot Water Pipes and High Efficiency Water Heater Upgrade.

- The HEMS included the installation of 30 wireless thermostats. Three different models were identified for installation: Trane, Ecobee and Nest (10 each). Along with the thermostats, T-Mobile hotspots were provided to facilitate wireless programming capabilities for the residents.
- The Cool Roof installed on the 10-plex building was comprised of Sprayed Applied Polyurethane Foam Roofing System (closed cell spray foam, brand SWD). This included priming of the roof deck with SWD 2000 sealer, an application of 1.5-inch thickness of SWD "Quik-Shield" 125 (2.5-3.0 lb.) density polyurethane foam to the roof surface, R 9.45, followed by an application of 1929-F "Quik-Shield" elastomeric base coating and application of 1929-F "Quik-Shield" white elastomeric top coating, and finished by broadcasting #6 granules into the wet finish coat.
- Within the dwelling unit, the dropped-ceiling drywall was removed, along with asbestos containing materials contained within the 'popcorn' ceiling texture and the drywall taping compound, exposing the duct chase above. This removal was completed by a certified asbestos mitigation technician. Once the space was cleared by the asbestos technicians, the existing ducts that were accessible were removed and discarded. After the old ducts were removed and before the new ducts were installed, the open and empty duct chase provided access to some ceiling bays between ceiling joists, as well as building interstitial space. Loose-fill fiberglass insulation was blown into the accessible attic bays, reaching as far into the bay as possible with the blown-in insulation. This additional insulation was not part of the original package of measures, but was identified during the pilot unit work as an opportunity to increase the energy savings without much increase in project cost.
- Existing refrigerators were replaced with current ENERGY STAR® models through the Southern California Edison's (SCE) Direct Install program.

- LED fixtures were used to replace 252 existing light fixtures that consisted of various wall pack fixtures, both Metal Halide and CFL, along T8 florescent lamps, and recessed cans.
- The photovoltaic system is a grid-tied system which interconnects with the existing electric distribution system at the Village at Beechwood site. It consists of 84 kw/dc of photovoltaic modules mounted on existing carport structures and (7) inverters with a total output of 70 kw/ac power.
- The Solar thermal system consisted of (12) collectors (from Jiangsu Sunrain Solar Energy Co. Ltd. Model:TZ58/1800-30R) installed on the roof of 10-plex building. On grade 1,250-gallon water tank with heat exchanger was installed, along with a monitoring system.
- The existing buried hot water circulation lines were abandoned and replaced with identically sized, new PEX hot water lines. New water lines were wrapped with FoamGlas Insulation and placed over sand bedding. Two of the three existing 100-gallon water heaters were removed. The third existing water heater remained and was augmented by a hot water pre-heat provided by the solar thermal system. A new high efficiency tankless condensing water heater, Rinnai RU98i, was installed in Building 20, replacing an existing 50-gallon water heater.

Table 36 enumerates the estimated budgets of the VER package.

Table 36: Comparison of Preliminary Budget to Contracted and Actual Cost

VER Package	Budget	Expected	Actual
HEM	$ 9,850.00	$ 7,448.00	$ 7,227.00
Cool Roof	$ 48,000.00	$ 46,489.00	$ 51,759.00
Air Leakage/Ducts	$ 231,000.00	$ 239,308.00	$ 243,689.00
Refrigerators	$ -	$ -	$ -
Lighting	$ 35,252.50	$ 35,252.50	$ 35,252.50
PV System	$ 341,000.00	$ 341,000.00	$ 341,189.37
Solar Hot Water	$ 89,980.00	$ 89,980.00	$ 89,980.00
High Efficiency Boiler	$ 6,350.00	Included in Insulated HW Pipes	Included in Insulated HW Pipes
Insulated HW Pipes	$ 24,000.00	$ 69,670.00	$ 70,302.00
Total	**$ 785,432.50**	**$ 829,147.50**	**$ 839,398.87**

Source: Electric Power Research Institute

- HEMS models were not selected until prior to installation. The budget amount included a material allowance. Once selected and purchased directly, the actual costs were less than anticipated.

- The increase in costs related to the installation of the cool roof was the result of two issues. The first was the removing the gravel material that was on the existing roof. The removal of this material was not anticipated at bid time, but was recommended by the installer. The 1.5 inches of foam roof required that the mechanical roof mounted pads be raised. During the execution of this work it was recommended that (10) sheet metal pans be added to the mechanical roof curbs to mitigate possible water intrusion.
- The increase in cost in the air leakage/duct package was related to the correction of errors made by the roofer during the execution of their work. This included the cutting of thermostat wires and misstep that caused a hole through the roof sheathing and drywall ceiling below.

The underground piping related to insulating the hot water pipes had the greatest difference from budget to actual. The circulation of the hot water was unknown at the time that the budget was created and therefore difficult to estimate. The scope was also increased based on recommendation of the selected bidder to include the replacement of some old valve boxes and upgrade the insulation material. During the execution of the work, there were some repairs to the water main that were required that also added to the cost.

Very Efficient Retrofit Package Installation and Commissioning

The energy efficiency (EE) measures installed in the 28 apartments was the first installation phase of this research project. The contractor was told to be prepared to adjust practices as needed to minimize disruption to the tenants and adjust quality of work to achieve aggressive gains in energy efficiency. The energy efficiency measures included standard weatherization improvements, typical, high-efficiency equipment/measures, and novel approaches to increase the efficiency of the multifamily dwelling units. The novel aspects had been tested and verified to improve the efficiency of the HVAC distribution system by replacing the existing supply ducts with new, R-8 flex-ducts, and by making proper connections such that leakage of the new ducts and their connections is near zero. After the supply ducts were replaced, the entire duct system was insulated to further increase duct-system efficiency. Part of the ductwork was exposed above the roof where the supply and return ducts connected to the RTUs. These exposed sections were coated with about ¾" of foam when the roof foam was sprayed. Following the installation of blow-in ceiling insulation and sealing of unwanted air paths, the old ducts that were removed were replaced with new, R-8 ducts using proper connection processes and procedures. Just prior to replacing the dropped ceiling the entire chase was filled with insulation to thermally isolate the ducts. Figure 40 shows some of the duct retrofitting process.

Installation of High Performance Ducts and Duct Sealing

Duct sealing and reduced air infiltration to improve the thermal performance of the apartments. The entire process consisted of eight steps, which is described below from A (test-in) to H (test-out). Steps A, D, and E were done sequentially, and Steps B and C were completed by the time Step E was completed (Figure 40). Steps A-E were performed on a maximum of two units simultaneously, and if two were performed simultaneously, they were stacked in pairs.

Figure 40: Retrofits to Achieve High Performance Ducts

Source: Electric Power Research Institute

A. Test-in: The following tests were performed on each apartment prior to any improvements, on the work-day immediately preceding step D. The test results were recorded on a data sheet Figure 41.

    a. "Duct Blaster" Test: Duct leakage was measured by pressurizing ducts to 25 Pascals (Pa) and recording the CFM needed to achieve a stable 25 Pa with the pressure-fan ("duct blaster") sealed to the return, and all supply ducts sealed with tape. Only painters' blue masking tape was used for attaching equipment (for example, Duct Blaster) to the apartment or to seal any registers, windows or doors.

    b. Duct Blaster with Blower Door: Test 1, Duct Blaster, was repeated but with Blower-door installed and pressurizing the ducts and the apartment both to 25 Pa. The CFM needed to achieve a stable 25 Pa with the Duct Blaster was recorded.

c. Envelope leakage ("blower door) test. Envelope leakage tests was performed on the apartment with all windows and doors closed (except the front door, where the blower door equipment & fan are installed). The apartment was tested at 50 Pa and the CFM needed to reach 50 Pa reported. If 50 Pa was not achieved, the actual pressure was noted on the datasheet.

d. Performed all four of the following tests:

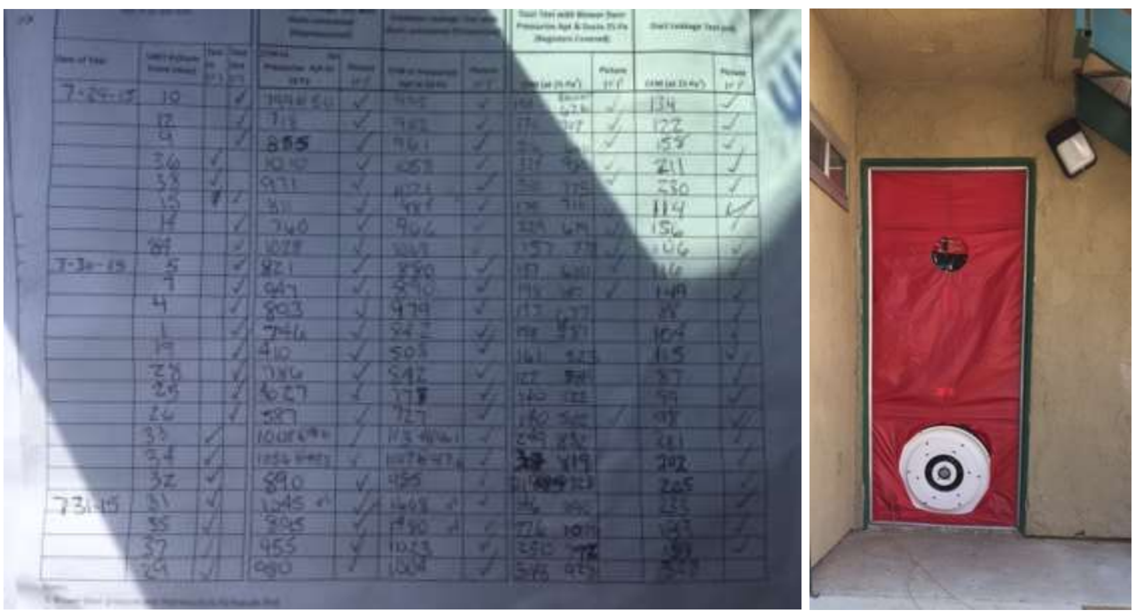
   i. Perform the blower-door test by pressurizing the apartment with the HVAC registers (both supply and return) taped closed.

   ii. Repeat the blower-door test by depressurizing the apartment with the HVAC registers (both supply and return) taped closed.

   iii. Repeat the blower-door test by pressurizing the apartment with the HVAC registers all uncovered.

   iv. Repeat the blower-door test by depressurizing the apartment with the HVAC registers all uncovered.

Figure 41: Blower Door Testing Sheet Data of the Final Commissioning



Source: Electric Power Research Institute

B. Envelope Sealing was performed only after Test-in.

   a. Used the blower-door, while envelope is depressurized to identify major leaks using smoke pencil or other techniques, so that they could be sealed.

   b. Sealed leaks and/or installed new weather-stripping in typical places and any identified during test-in and/or while the apartment is pressurized specifically to find and identify leaks; included weather-stripping and/or sealing, as appropriate around entry door, sliding door, windows, and exterior floor and ceiling joints.

c. After sealing was deemed completed, tested actual leakage with blower-door test. Target leakage was 3.0 ACH50., which was, for 1, 2, and 3 bedroom apartments, 233, 295, and 407 CFM50 respectively. If envelope leakage was higher than the target value, attempted to find and seal additional leaks to reduce leakage to or below the target.

C. Sealed rooftop supply and return duct segments: The “L” ducts between the rooftop package units and the roof / roof penetrations were sealed and painted. This step was done at a time after test-in and before test-out of each apartment. Light-colored UL-181 approved duct mastic was applied to all accessible connections in these duct segments between the rooftop package units and the roof to cover the existing mastic and to seal any leaks. After the mastic was cured, cover both duct segments with white, reflective roof paint. Care was taken to not disturb the existing mastic.

D. Ceiling Removal and asbestos abatement: This step was done in conjunction with Step E to minimize disruption to the tenants, who were out of the apartments during retrofit working hours, and back in the apartments between 5 p.m. and 8 a.m. each day, for a maximum of 4 days for a pair of apartments. Removed all existing drop ceiling (entry and hallway outside bedrooms) using proper asbestos abatement protocol, and dispose of asbestos-containing drywall at legal dump site and provide documentation of legal disposal. Asbestos removal scope and work practices included were: full negative pressure, containment with high-efficiency particulate air (HEPA) filtration, and wet method with HEPA vacuuming. Occupational Safety and Health Administration compliant respiratory protection and suits were used. Asbestos Containing materials were located as follows:

a. Removed existing supply flex-ducts that were accessible and replaced with R8 flex duct. All connections were performed according to duct sealing standards.

b. Sealed return joints – This was a repeat of the note at the top of this section. During the pilot, it was determined that there was very limited access to the return duct, which was metal, with joints connecting duct sections. Leakage typically occurred at these joints, which were not accessible from the outside, and were therefore attempted to be sealed from the inside. The most reasonable approach determined was to seal the joints in the hard-ducted returns using an aerosol-sealing approach. The research team worked with the Western Cooling Efficiency Center at UC Davis to find a qualified contractor or a good approach to outfitting and training the LINC contractor of choice for the bulk of the retrofit work.

c. Verified that the final duct leakage met or exceeded the performance goal of no more than 10 percent total duct leakage. Some pictures of the retrofitting process are shown in Figure 42.

i. Performed a duct-blaster test as described in Section A.1. Duct leakage was not to be more than 80 CFM_{25}.

ii. If this goal was not met, diagnostic measures would have been taken to find leaks and seal them, then step E.2.a repeated. If necessary, we would have cycled through steps E.2.a – E.2.b until the duct leakage target of 80 CFM_{25} was met.

Figure 42: Duct Retrofitting in Progress

Source: Electric Power Research Institute

d. Tested duct leakage after installation of new ducts in both apartments. Final duct leakage was to be no more than 80 CFM at 25 Pa (target 10 percent of unit nominal airflow - 400 CFM/ton x 2ton = 800 CFM; 10 percent = 80 CFM).

e. Paid attention to both supply and return ducts, and used unfaced batt and loose-fill insulation materials, completely filled the space in the duct chase to maximize the insulation of both supply and return ducts. Took the recommendation for applying batts prior to replacing drywall and loose-fill after drywall is in place (inserted through hole(s) made in plenum and repaired afterwards). After completing this step, estimated the average thickness of insulation for each of supply and return, and recorded this number at the completion of retrofit.

E. Range Hood Exhaust: After Test-In, but prior to Test-Out, installed a damper in the exhaust duct from range hood.

F. Restore Ceiling: installed 5/8" drywall to replace removed drop-ceiling; mud and taped drywall to smooth finish and painted.

G. Test-out.

Upon completing steps A-G, the research team completed test-out procedures and followed the same procedures used in steps A.a and A.b (duct leakage and envelope Leakage tests). The goal leakage rates were met and verified by tests during/after sealing the ducts, and during sealing the envelope. Nonetheless, this test-out was performed after all steps during the retrofit were verified to meet the performance goals described in this section.

1. Retested duct leakage after installation of new ducts in both apartments. Final duct leakage was no more than 80 CFM at 25 Pa. (Test-out for ducts)

2. Performed test-out for envelope leakage using blower-door. Target leakage is 8.5 ACH50, which was for 1, 2, and 3 bedroom apartments, 636 CFM50, 807 CFM50, and 1,112 CFM50, respectively (807 CFM50 for the prescribed 2-bedroom apartments).

Location / Material	Extent of Asbestos Contained
Accoustic Ceiling Materials	Throughout Apartments except Kitchen and Baths
Drywall Joint Materials	All Wall and Ceiling Drywall Joints
Silver HVAC Duct Mastic	Roof-Mounted HVAC Ducts
Grey Roof Penetration Mastic	Roof Penetrations on All Builidings
Exterior Stucco	All Exterior Walls (Stucco)
Vinyl Flooring and Adheasives	Kitchen and Bathroom Flooring materials
Transite Vent Pipes	Roofs of all Buildings

Upon removing the ceiling and exposing the ducts, the materials were inspected using an appropriate asbestos contractor.

Water Heating in the Multiplexes

The efficient water heating (Figure 43) problem for the apartments was solved by the use of solar hot water with gas backup. This solar option was installed by Everyday Energy. For this work, the research team reroofed Building 3 and placed the solar thermal system on the rooftop of that building. The systems installed are listed in the following:

- 24 evacuated-tube solar water-heating collectors from Jiangsu Sunrain Solar Energy Co, Ltd., Model: TZ58/1800-30R.
- Water Tanks: 2 at 1,250 gallons with heat exchanger.
- Crane rental.
- Custom pipe covers.
- Engineering and permits.
- New electrical circuit installation.
- Slab and fencing for tank.

- System monitoring 5 year (small).

Figure 43: Water Heating in Mechanical Closet

Source: Electric Power Research Institute

The gas backup was provided by a boiler recently purchased to replace an old, recently failed boiler. This system required replacement of the existing distribution piping from the central boilers to the buildings. This was achieved by abandoning the existing piping, and installing new, 2” diameter insulated copper water-distribution lines on the roof of one of the buildings (Figure 44).

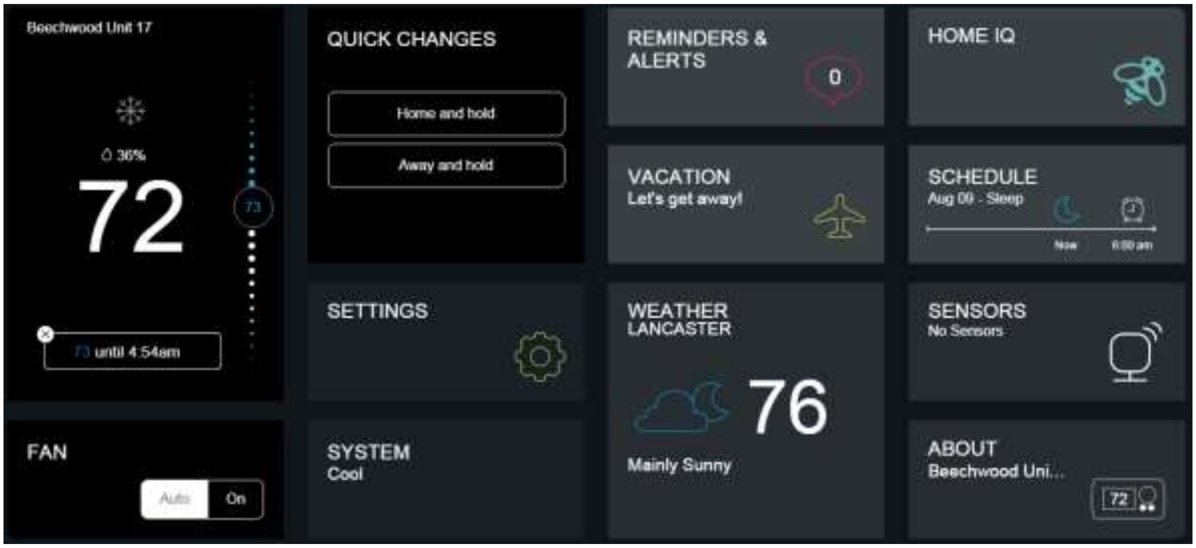
Figure 44: Solar Thermal System Installation and Commissioning

Source: Electric Power Research Institute

Home Energy Management System

Smart thermostats were installed as the center piece of the HEMS system (Figure 45). The HEMS ecosystem allowed control of many points from the interface of the thermostats, such as lighting control, security control and blinds control in addition to the primary function of allowing users to set climate control schedules on the user interface directly or from their smart phones remotely. Ecobee, Trane Nexia and Nest Thermostats were installed in the apartments (10 of each brand) and their installed pictures is shown in Figure 46. The HEMS system was designed to collect data on occupant interaction (such as thermostat temperature adjustment) with the permission of the occupant. This understanding assisted in separating technological and behavioral components of energy use.

Figure 45: Smart Thermostat Control Interface



Source: Electric Power Research Institute

Figure 46: Installation and Commissioning of Home Energy Management System

Source: Electric Power Research Institute

Installation of Reroofing Using Polyurethane Spray-Foam with Elastomeric Coating

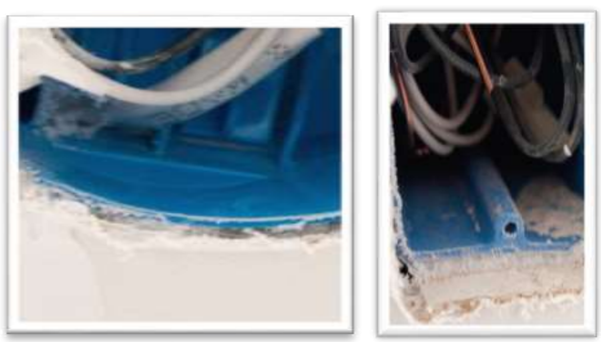
This measure was included on the VER package. The roof and HVAC ducts exposed above the roof of the community center both benefited from reductions in air leakage and improvements in insulation levels. Spray-applied polyurethane foam insulation (SPF) provided both air sealing and a layer of insulation. This task focused on the issues that are unique to multifamily applications, specifically how to deal with the possibility of sealant material traveling from one apartment to another, or being wasted through large penetrations to piping chases. Two primary objectives of employing aerosol technology were as follows: 1) test the practical effectiveness of the aerosol-based envelope sealing methodology in the common area of Beechwood Complex, and 2) estimate the first-cost savings and heating/cooling load reductions that could accrue from this type of sealing.

SPF is formed when two liquid components are mixed at a 1:1 ratio inside a specialized spray gun, which generates tiny bubbles with isocyanates, polyols, catalysts and a non-ozone-depleting blowing agent when the mixture is sprayed. The bubbles can expand 30 to 50 times larger than its original volume to insulate the roof. SPF is widely used for residential and commercial buildings with old and leaky flat or low-slope roofs. SPF offers high R-value that resists solar heat gains, long service life that should last the life of the house and only requires ultraviolet resistant coating every 10 to 15 years. SPF is water resistant; water leakage only occurs if some foreign object penetrates the foam, producing a hole in the roof through which could leak.

Aerosol Building Envelope Sealing Technology

The aerosol building envelope sealing technology, shown in Figure 47, was developed by researchers at the University of California, Davis Western Cooling Efficiency Center (WCEC).

Figure 47: Aerosol Space-Sealing Test for Air Change Rate



Source: Electric Power Research Institute

Previous tests have shown a reduction of 50 percent in leakage areas. The researchers believed in its potential to further reduce building leakage area. This technology used a compressed nitrogen nozzle to aerosolize the liquid sealant and disperse the aerosol sealant under pressure into the house. The sealant follows small air-streams that form in and around the leaks; however, the mass of the aerosol causes the particles to hit the edges of the leaks, at which point some of the particles will stick to the edge. Over time, a deposit of the aerosol particles builds up in and around the leaks, sealing them.

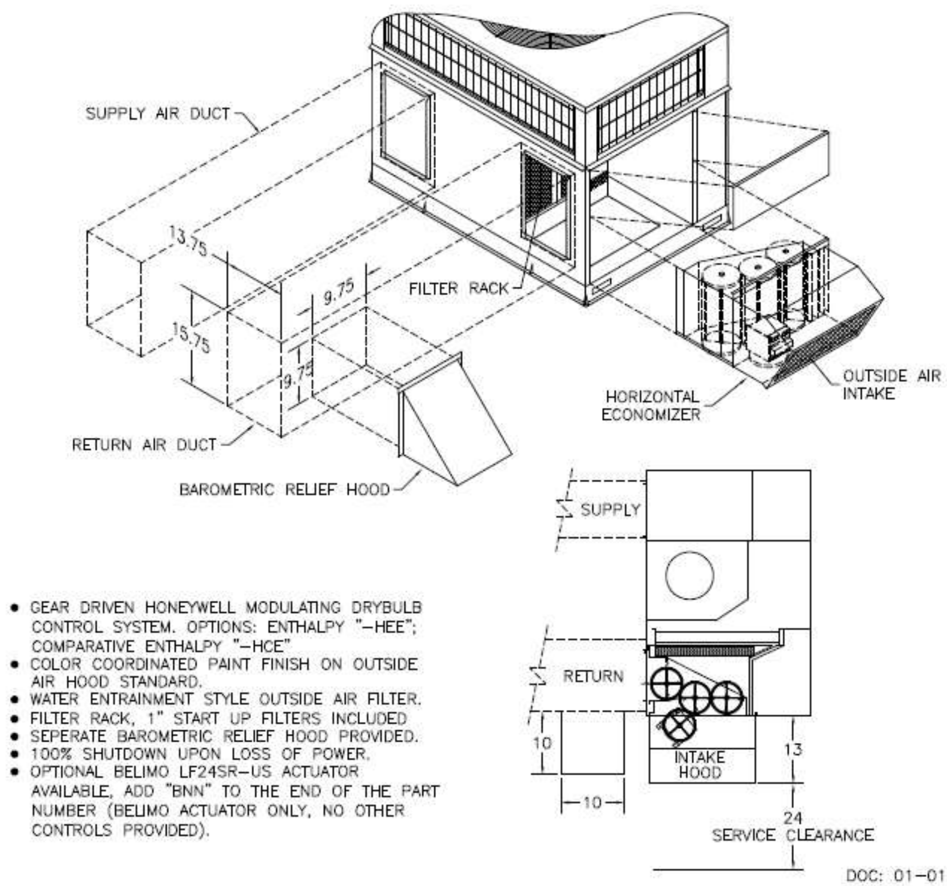
Aerosol sealing for building envelopes has had a much shorter time in the market as compared to aerosol-based duct sealing. In the case of envelope sealing, the technology for enabling and controlling the process, namely a blower door, was already in widespread application throughout the state. At the time of project execution, the blower doors could both maintain the required pressure difference across the building envelope, and had software to track the leakage while the aerosol does the sealing. The remaining issues revolve around the best choice of sealant material/injector, and application-specific issues. Good progress on the former was made under WCEC support by the Public Interest Energy Research Program.

Economizer on the Common Area Rooftop Units to Utilize Cool Outside Air

The Economizer circulates fresh outside air into the building and encourages a healthier environment for occupants by minimizing recirculation of stale air. It also extends the life of rooftop units if the settings are correct (for example, temperature set points and minimum outside air damper position), because the compressor work is reduced when more outside air cooling is used.

The installed economizer was compliant with California Title 24 Building Efficiency Standards. The dampers were low leakage at 3 percent to 5 percent, exceeding Title 24's specification of 10 percent at 1-inch water column static pressure. The economizer installation (Figure 48) was installed on the 2 ton and 4-ton Carrier RTUs and the energy saving impact was estimated by switching the staging of the compressor when outside air meets the criteria.

Figure 48: Dedicated Horizontal Economizer



Source: Electric Power Research Institute

The field test focused on the energy savings from the compressor switching, using less mechanical cooling to provide comfortable indoor air condition.

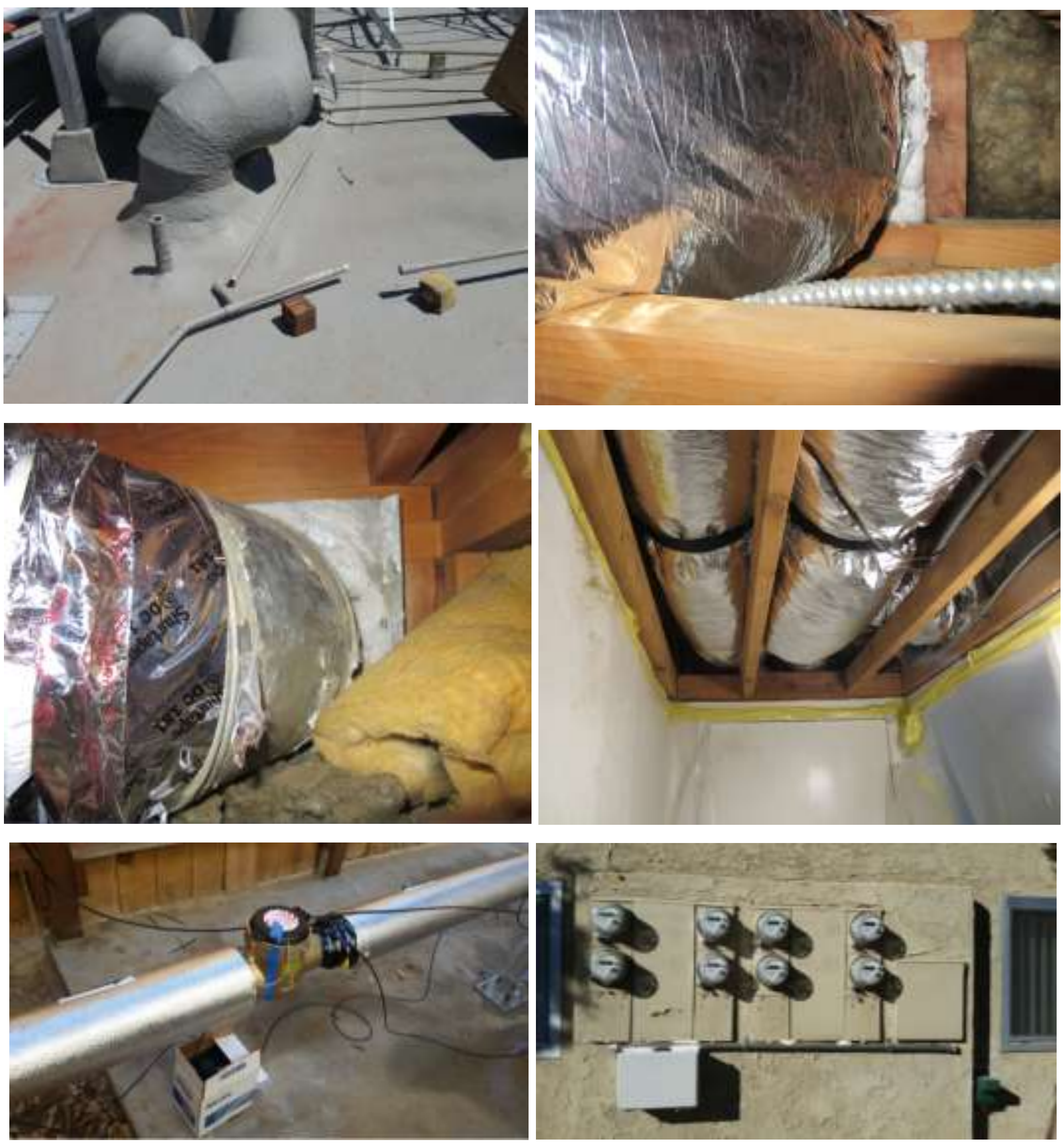
Tankless Water Heater

Tankless water heaters were installed to provide domestic hot water. Efficiency was improved by about 20 percent because of reduced standby losses. In addition, the tankless water heater provided an unlimited supply of hot water. The technology itself was not new at the time but due to high upfront cost, the simple payback could be as high as 20 years or more.

Evidence of Post-Retrofit installations.

Figure 49 shows post retrofit installations.

Figure 49: Post Retrofit Installations



Source: Electric Power Research Institute

Methods Developed to Assist Installation and Commissioning

Method to Obtain Cost Estimates

LINC Housing, LLC hired a construction management firm to provide some preliminary pricing based on the contemplated scope of the project. This exercise led to further definition of the VER packages and the establishment of the budget. This same construction management firm subsequently created "Instructions to Bidders" that was circulated to bidders for the HEMs, cool roof, air leakage/ducts, and hot water piping insulation and water heater upgrades. Separate from this effort, multiple bids were solicited for the PV and solar thermal packages. The lighting retrofit work was contracted and managed through a utility incentive program.

Method to Choose Subcontractors

Some packages, like refrigerators and lighting, were also dealt with directly through a utility incentive programs. To find qualified bidders for the other VERs, the team consulted the Energy Upgrade California website that provided access to a database of licensed contractors with experience in energy retrofit work. Local vendors that had previously done work on the property and were familiar with the facility were also contacted. Various team members also made recommendations based on contractors and relationships from previous projects. More than 15 contractors were provided with an invitation to bid. Of these, 10 contractors attended a job walk and ultimately provided pricing. The proposals provided by these contractors were compared and leveled to determine the lowest, qualified bidder.

Method to Obtain Final Cost Estimates for Packages

An Invitation to Bid was distributed to solicit interest for those packages that were not being installed through a utility incentive program. Those contractors that responded with interest received Instructions to Bidders and attended a job walk for clarification of the scope of work. When the proposals were received, they were reviewed for accuracy, evaluated for completeness and the lowest qualified better selected.

The HEMs, being a relatively new technology, required, ultimately, that the team work directly with the vendors to purchase the thermostats as these models were not locally readily available in local home improvement stores.

Method to Optimize Packages to be within Budget While Maintaining Very Efficient Retrofit Goals

One good example was that during the bid process, the plumber suggested for the insulation material to be installed around new hot water lines. This product, FoamGlas, proved to be superior to the product recommended for bidding.

Much time and consideration went into to the preliminary planning and budgeting phase of the project; thus, final costs were relatively close to those projected.

Discussion of Variances

Asbestos mitigation was the single largest variance between the original planning and final the costs of the actual retrofits, and the limiting factor on the installation of the retrofits. Problems/issues included:

- Access to most of the ceiling area to install insulation.
- Limited access to the ducts; for instance, unable to find a practical way to have access to the return ducts to seal them).
- Variability in duct locations: the asbestos was removed by an asbestos contractor who cut an opening where instructed. The instructions came from the contractor, who had limited information regarding duct locations, and there was no way to adjust in the opening because the area was sealed-off during the retrofit to contain and abate any free asbestos.

In addition, following are the breakdown the different variances:

- Variances from the original EE Package designs and reasons for the variances:
    - Asbestos in the acoustic ceiling and drywall mud affected not only cost greatly, but reduced the effectiveness of the duct work and insulation measures.
    - Adding blow-in attic insulation was an additional measure added. This could have been much more effective for less money had it not been for the asbestos.
    - Aerosol sealing for the common area left sealant in the carpet and furniture (which should have been covered prior to the sealing process) that required additional effort to clean.
    - Using Hotspots as Wi-Fi connections caused internet connection issues, which made data collection from smart thermostats and NILM systems difficult.
- Descriptions of the EE package installations and any important variants from the anticipated installation processes:
    - The field crew did not receive the correct test-in/test-out procedure, so additional quality control and training were required in the field. The crew was not fully trained on measuring air leakage leading to some questionable test results (especially the duct leakage to the outside, which was consistently measured incorrectly).
- Descriptions of any installation variants encountered and how they were mitigated or otherwise handled:
    - Existing ductwork varied between buildings, but the crew was able to replace the ductwork. They also smoke tested the ducts to find and seal leaks in the RTUs (after the initial duct replacement/ sealing work). Aeroseal sealant was cleaned by WCEC. The cleaning result was satisfactory.

- Anticipated impacts on EE package performance due to any installation variants:
    - The insulation levels/coverage over the bedrooms and living room varied depending on existing framing conditions (like the mid-span blocking that may or may not have been installed between the joists at the time the building was constructed).
- EE training was provided to tenants:
    - Everyday Energy trained some of the tenants on installation of PV arrays. Smart thermostat installers trained some of the tenants (if the tenants were at home during the installation).

Chapter 7: Very Efficient Retrofit Package Post Retrofit: Occupant Education, Evidence, and Customer Feedback

Customer education was accomplished through training and education events. Occupants of the retrofitted homes experienced much improved comfort levels. For example, an occupant mentioned that her child could now sleep during the night because the retrofit provided a much cooler space. EPRI, LINC, and SCE have co-hosted customer education covering topics such as ZNE and the energy upgraded work performed onsite. Customer interviews and education materials are documented.

Education Opportunities for Occupants

As part of the solar PV retrofit, Everyday Energy conducted training on solar installation basics and provided certificates to the occupants who passed the course. One of the biggest outcomes of this effort, more than the training itself, was the confidence and the pride it instilled in the tenants who participated (Figure 50). The tenants were also connected with local job centers to further leverage their learning in the solar installation business. Based on the success of the training, LINC has partnered with Grid Alternatives, who have a sizeable training component, for future solar installation projects.

Figure 50: Occupant Interview and Education Event

Source: Electric Power Research Institute

Tenant Interviews

SCE conducted interviews of the tenants after installation to get their input on the retrofits and gauge customer satisfaction (Figure 51 through Figure 53). The overall feedback was greater comfort and quality of living. The occupant interviews were conducted by Lori Walker, who works at SCE's Customer Insights program.

Figure 51: Occupant (1) Interviewed on the Near Zero Net Energy Retrofit

This occupant was very happy with the retrofit and she said "Very good, you turn on the air and the house gets cold in a matter of minutes."

Source: Electric Power Research Institute

Figure 52: Occupant (2) Interviewed on the Near Zero Net Energy Retrofit

The occupant complimented the energy efficiency retrofit and said the "insulation kept the (conditioned) air in the apartment longer", which saves energy.

Source: Electric Power Research Institute

Figure 53: Occupant (3) Interviewed on the Near Zero Net Energy Retrofit

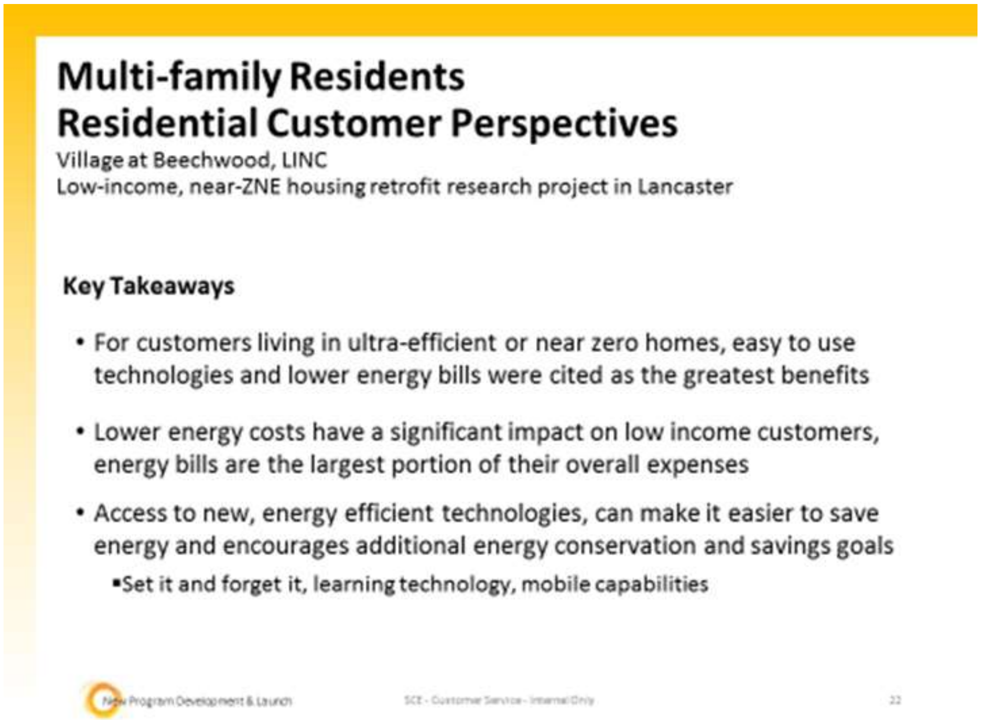
This occupant now estimated to keep her bill around $30 - $35 per month, which fits in her budget now. Her energy bill could go up to $150 per month. She smiled and commented that "It is a big change."

Source: Electric Power Research Institute

The program has summarized the following points from the video clips of occupant interviews and also provided the implications from the customer interview (Figure 54).

- Residents were thankful for the energy upgrades and happy to be part of the test project.
- Not everyone has experienced a lower bill but many reported 20-50 percent reductions in utilities.
- The upgrades did not alter energy behavior for any of the residents.
- All the residents reported the heating and cooling to be very effective and efficient, with the home very quick to reach and sustain desired temperatures.
- Residents who had downloaded the app were happy to be able to control their heating and cooling from their smartphones. Some had technical difficulties post-set up.
- The expectations of savings for retrofits need to be explained to consumers so they understand impacts to bills.

Figure 54: Key Takeaways of Customer Interview



Source: Lori Walker, Southern California Edison

Some of the residents were concerned with the increase in their bills coincident with the retrofits of the apartments. When this was investigated, one of the causes identified was the change from SCE to City of Lancaster Community Choice Aggregation (CCA). The combination of losing the California Alternate Rates for Energy (CARE) rates provided by SCE and the additional transfer fees from being part of the CCA showed up as an in increase in tenant bills. If this is a consistent pattern, then even if CCA's on average show small reductions in energy charges for their constituents, there is a concern that there might be skewing with prices increasing for low-income tenants and reducing for larger users.

CHAPTER 8: Data Analysis

Data Analysis Plan

The team was able to leverage EPRI's past experience in large scale data collection, and using existing data sources from residential buildings for energy efficiency analysis. To identify, synthesize, and manage data from multiple sources also requires the appropriate advanced analytical tools to assist decision making. This required the team to develop a suitable data monitoring plan at the beginning of the project and then establish a data warehousing strategy that collected data from many sources. The team also developed suitable statistical tools to analyze datasets using a method scalable to any size of residential communities for energy efficiency and ZNE analysis.

The data collection and analysis plan included three steps:

1. Step 1: Choose the most relevant data.
    a. Automated metering infrastructure (AMI) data were recordings of the household's electric energy consumption on an hourly or shorter basis. The energy monitoring and load disaggregation system leveraged granular AMI data to understand the household's energy use patterns and occupant behavior.
    b. Thermostat data and/or the temperature data in the ducts, to show the temperature set points and the room temperature recordings, which reflected the heating/cooling pattern, occupant comfort level, energy performance of the building, and potential of HVAC upgrades. This data also helps to identify target households when compared with data from similar homes in the community or locations nearby.
    c. Monthly natural gas consumption data. When coupled with outside air temperature, this helps understand the household's energy performance.
    d. Billing data to show the electric expenses and overall usage.
    e. Solar PV and/or solar thermal related energy data.
    f. Commissioning data or worksheets to show the improvements done onsite and make sure the equipment and upgrades are installed and operating as expected. The data collection plan required the team to gather the data from multiple sources into a 'data warehouse', and to correlate those many channels to facilitate the data analysis.
2. Step 2: Develop site-specific data acquisition strategy to gather data into the "data warehouse." This step is described in detail in Chapter 5.

3. Step 3: Employ suitable tools and conduct data analytics. This step was conducted in six stages, described in more detail in the following sections.

    a. The first stage was the simulation analysis, and it went through the entire project. The purpose of simulation analysis was to identify the EE measures of the VER package and their contributions of energy savings of the package.

    b. The second stage focused on the energy efficiency improvements after duct sealing, insulation and smart thermostats that were implemented in June and July of 2015, and used five months of data collected from May to September in 2015 for analysis. The analysis showed substantial impacts on HVAC energy use reduction and improved comfort for occupants.

    c. The third stage was conducted in October 2016 after most of 2016 summer data has been collected so that the research team could compare the pre- and post-retrofit and investigate the energy efficiency improvements and the impacts to the community on both electricity and gas use.

    d. The fourth stage focused on the whole premise based on the NILM technology to study and load shapes and customer behavior of low-income community.

    e. The fifth stage was focused on the energy use of the common area.

    f. The sixth stage was focused on the electric and natural gas use and billing data of the entire community of the Village at Beechwood, in the absence of the individual unit's data.

First Stage: Simulation Analysis

Simulation analysis went through the entire process of this project. When the research team began the project, it conducted simulations as part of the energy audit process to establish the baseline energy use for the different apartment and building types (see Chapter 2). Chapter 2 also provides in-depth explanations regarding models, building simulations, input data, and simulation results. Simulations evaluated the VER packages, both feature by feature and as a whole package (see Chapter 3). The simulation results identified the potential energy savings of each EE measure of the VER package. At the final stage of this project, the team employed simulations to identify the energy savings by measure with a calibrated simulation model. The data shown and discussed in this Chapter are simulation results from simulation software calibrated against measured data, where possible. Such simulation calibrations have been performed on several different projects, using both new and retrofit homes and both single-family and multifamily buildings. Building simulation results and comparisons to measured data, where they were available, are discussed in this Chapter.

Simulation Analysis of Building 1

After providing the physical dimensions of Building 1, the team developed the BEopt energy model. The latest version (2.6) is the first to allow input from low-rise buildings with fewer than four stories. Version 2.6 can also provide a rendering of the building, which can be useful in checking the simulation input data (Figure 55). Using the simulation results from the hourly models, the team investigated the impact of various EE measures on the improved baseline features.

Figure 55: 3D Rendering of Building 1 (unit 1-8)

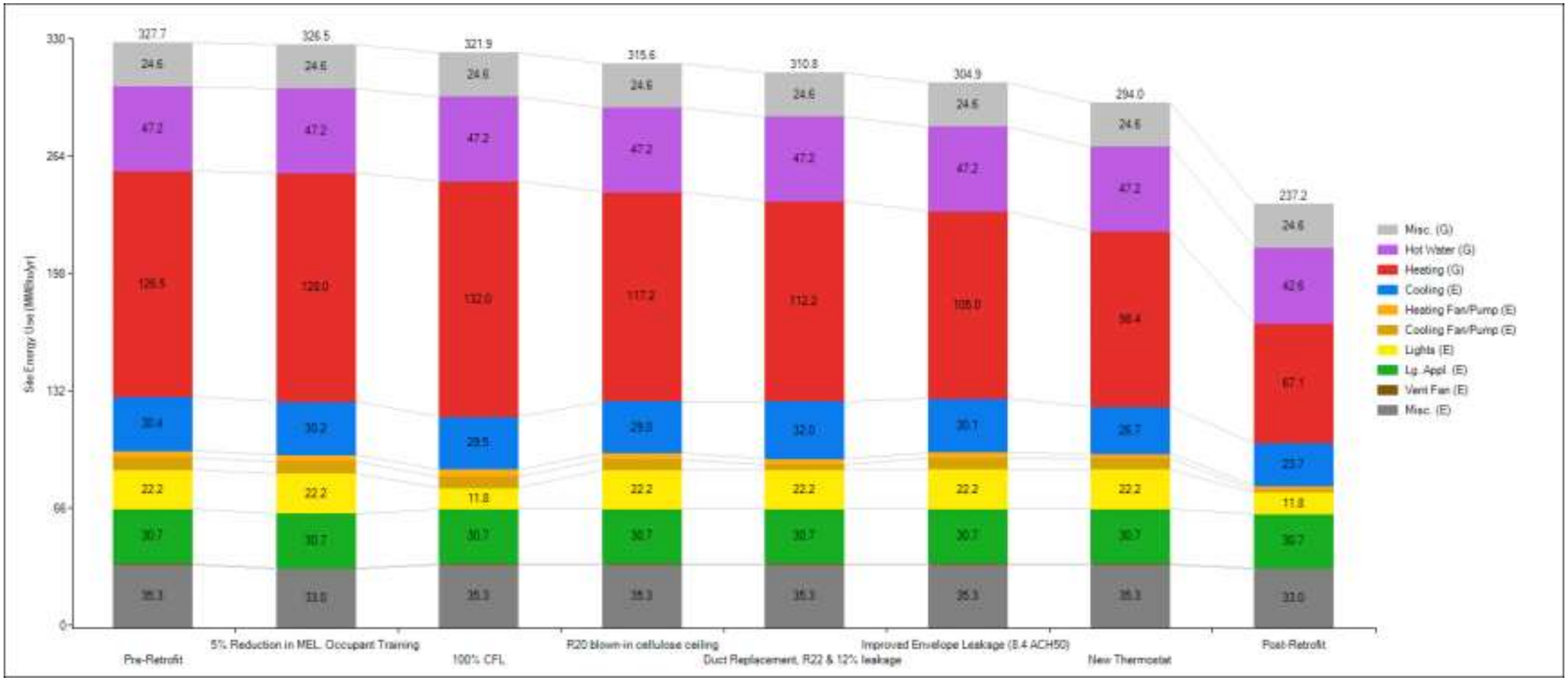
Source: Electric Power Research Institute

Figure 56 illustrates the site energy impacts of each of the individual EE measures on the Building 1 baseline model. Each bar in the series provides the results of a full-year simulation, with each energy end-use modeled represented as a block within a column of blocks for each modeled end-use. The blocks in each column are color-coded by end use types. The left-most column represents the total site energy use, in million British thermal units per year (MMBtu/yr) of Building 1 prior to any retrofits. The total of all the end uses is 327.7 MMBtu/yr, as indicated at the top of the bar. The next bar to the right provides simulation results when one of the energy-efficiency features is improved from the baseline. This second column shows the impacts on all end-uses when this single feature is made more efficient.

This type of analysis is called a single-feature substitution (or sensitivity) analysis, and in this case the improvement is in the amount of MELs. Those input values within BEopt are based on historical data from studies where occupants are provided with training on how to decrease their use of electricity, specifically the electricity used when plugging an electric appliance into an outlet and turning the device on. The overall savings is very low (1.2MMBtu/yr) and is distributed across three end-uses: MELs, space heating and space cooling.

The five bars to the right of the MELs bar provide the same type of information as the first two for different efficiency features. Each bar except the first (far left) and last (far right) provides the results from a single-feature substitution analysis. Thus, each bar provides the changes, if any, to each end use, as well as the sum of all end uses, shown as the total annual energy use for each of the single-feature replacements.

Figure 56: Site Energy Use of Building 1



Source: Electric Power Research Institute

As indicated by the description below each bar, this set of single-feature substitution analyses test the impacts of improving: MELs (training); lighting to CFLs; ceiling insulation to R-20; replacing ducts and increasing the surrounding insulation to R-20 and reducing leakage to 12 percent of total airflow; tightening the envelope to reduce the air leakage in and out of the home; and new, smart thermostats. For detailed descriptions of each of these features, see Chapter 4.

The last bar on the right shows the results of combining all measures in the VERs package. The results include interactions between features and diminishing returns due to more than one feature affecting the various end uses.

Results from Building 1 (Figure 58 and Table 38) are given for the whole building (eight 2-bedroom apartments). Figure 57 shows results from the same single-feature substitution analyses plotted previously for electricity only in units of kWh/year. All the other characteristics for the analysis in this figure are the same as the previous figure. Notice also that the value of each end use is provided in the center of the bar. These graphical features are to aid in visualizing any changes in a single end-use compared to its neighbor.

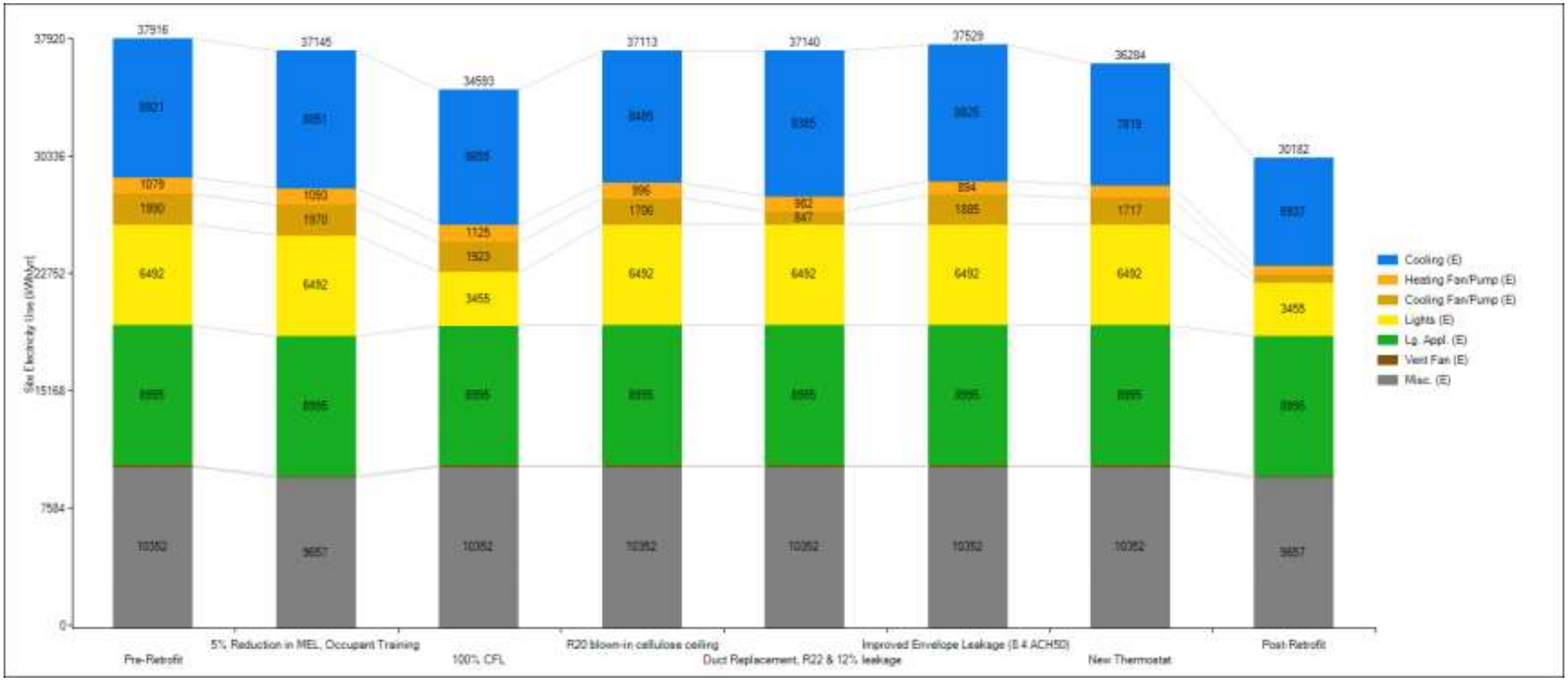
Table 37 shows the differences in electricity use across end uses for the single-feature substitutions (SFS) whose results are shown graphically in Figure 57. Numbers in parentheses are negative values.

Figure 58 represents whole-building natural gas budgets. All the other characteristics for the analysis in Figure 58 are the same as in Figure 57.

The results in Table 38 are average therms savings per apartment for Building 1. This table is essentially the same as the previous table except that Table 38 provides the changes in natural gas end uses for each SFS compared to the baseline pre-retrofit, reported in therms. Thus, Table 38 is a numeric chart of the differences in natural gas use across end uses for the SFS whose results are shown graphically in Figure 58. Table 38 also provides the changes in natural gas end-use for each SFS compared to the pre-retrofit baseline.

The percent savings per each individual EE measure, when added to the Building 1 baseline model was also calculated from the SFS simulations. Table 39 provides the predicted savings for each of the VERs as a percent savings of total energy use produced for each EE measure. The percent savings are from comparisons to the Building 1 baseline model.

Figure 57: Kilowatt-hour Use of Building 1



Source: Electric Power Research Institute

Table 37: Kilowatt-hour Savings of Building 1

Site Electricity Savings (Average kWh/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	Post-Retrofit
Misc. (E)	-	87	-	-	-	-	-	87
Vent Fan (E)	-	-	-	-	-	-	-	-
Lg. Appl. (E)	-	-	-	-	-	-	-	-
Lights (E)	-	-	380	-	-	-	-	380
Cooling Fan/Pump (E)	-	3	8	35	137	13	34	183
Heating Fan/Pump (E)	-	(1)	(6)	11	12	23	32	64
Cooling (E)	-	8	33	57	(57)	12	139	255
Total	-	96	415	103	92	48	205	968

Source: Electric Power Research Institute

Table 38: Simulated Therms Savings of Building 1

Site Natural Gas Savings (Average Therms/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	Post-Retrofit
Heating (G)	-	(2)	(7)	12	18	27	35	74
Hot Water (G)	-	-	(0)	0	-	0	-	6
Misc. (G)	-	-	-	-	-	-	-	-
Total	-	(2)	(7)	12	18	27	35	80

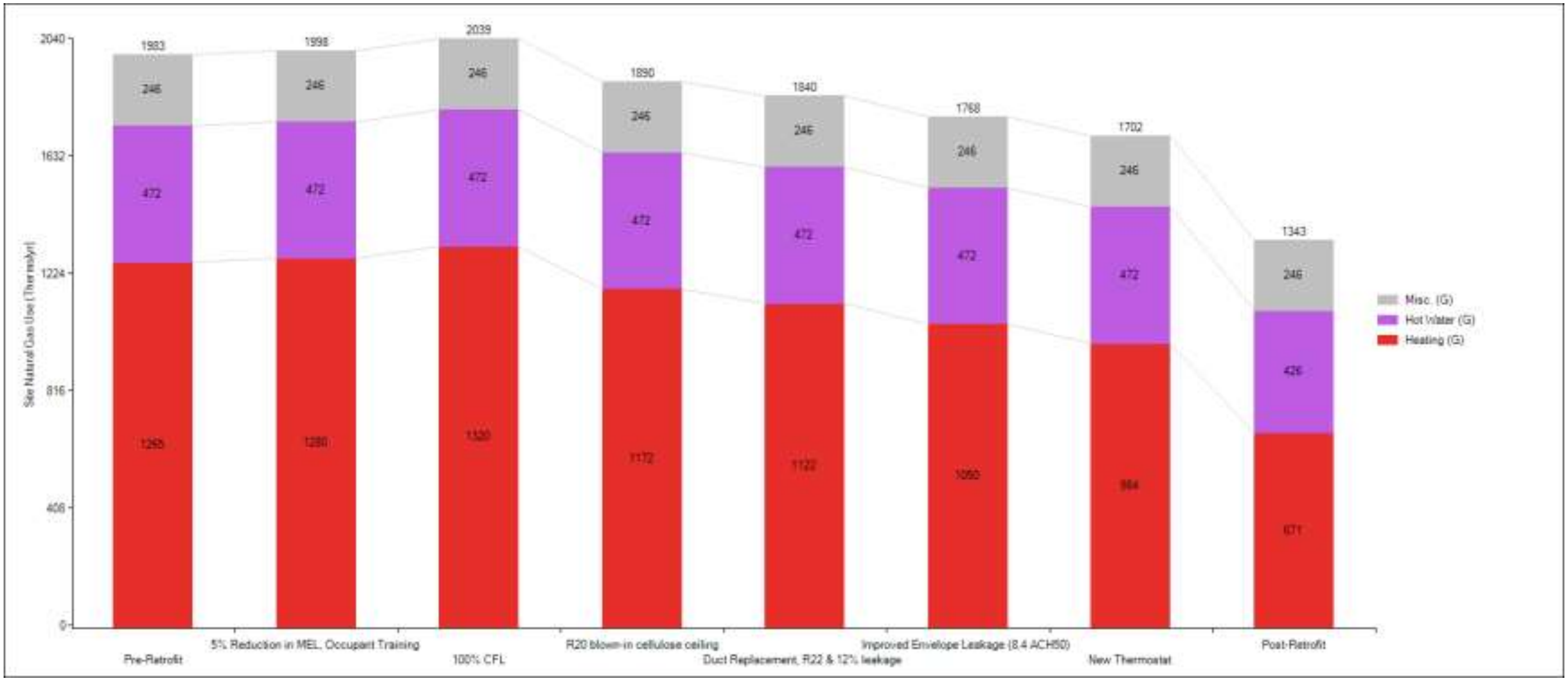
Source: Electric Power Research Institute

Table 39: Simulated Kilowatt-hour Savings of Building in Building 1

	% Savings
5% Reduction in MEL,	-1%
100% CFL	-3%
R20 Attic blown-in cellulose, ceiling	5%
Duct Replacement, R22 & 12%	7%
Improved Envelope Leakage	11%
New Thermostat	14%
VER Package	32%

Source: Electric Power Research Institute

Figure 58: Therms Use of Building 1



Source: Electric Power Research Institute

Notice in the total percent savings shown in Table 39, the savings are negative for the first two features, reduced MELs and changing lamps to CFLs. These negative values are due to increased energy use required for space heating for each improved case. In each case, there is a decrease in waste heat generated by the feature, but the amount of space heating required to compensate for the decreases in waste heat into the apartment from the more efficient cases is greater than the energy savings from the improved feature. Thus, the total energy savings for these two features are negative compared to their base cases. However, if calculated in TDV, these features produce savings.

Simulation Analysis of Building 2

As with Building 1, Building 2 was also modeled simulated using BEopt v2.6. A graphical representation, generated using BEopt is shown in Figure 59. Using the simulation results from the hourly models, the team investigated the impact of various EE measures on the improved baseline features. See below for the site energy impacts of the individual EE measures on the Building 2 baseline model.

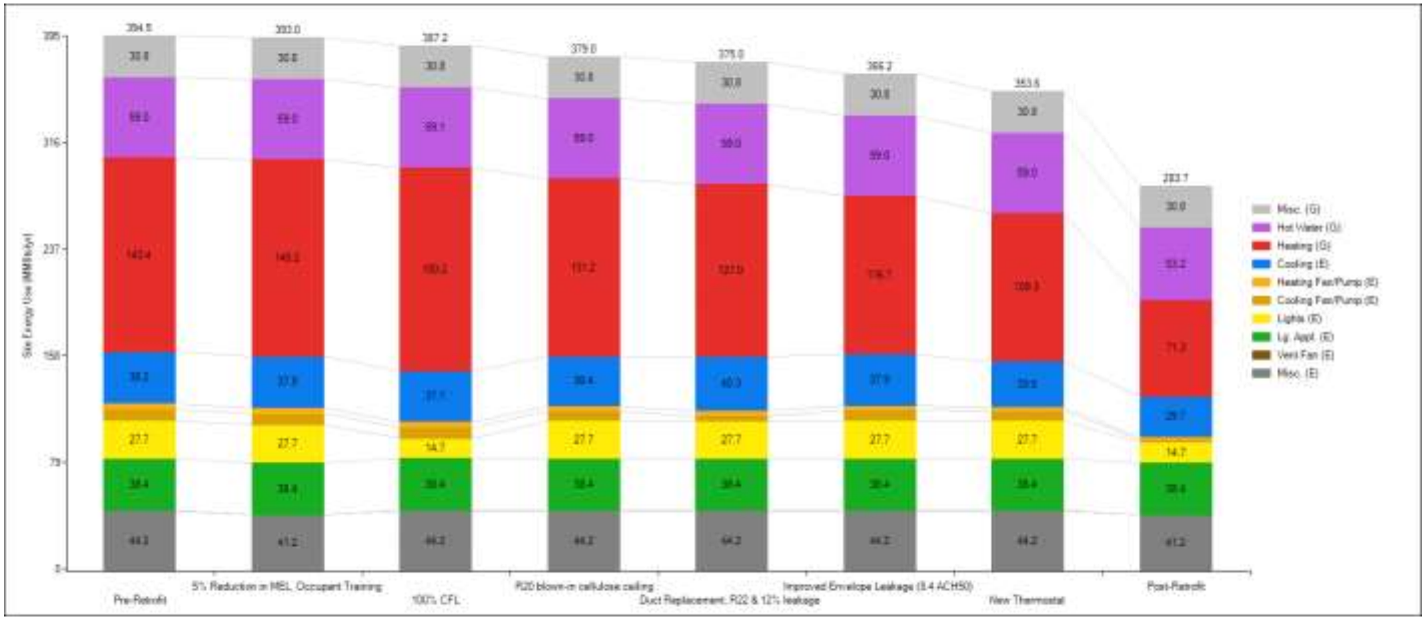
Figure 59: 3D Rendering of Building 2 (unit 9-18)

Source: Electric Power Research Institute

All the other characteristics for the analysis of the result for the Building 2 model are the same as for the previous model.

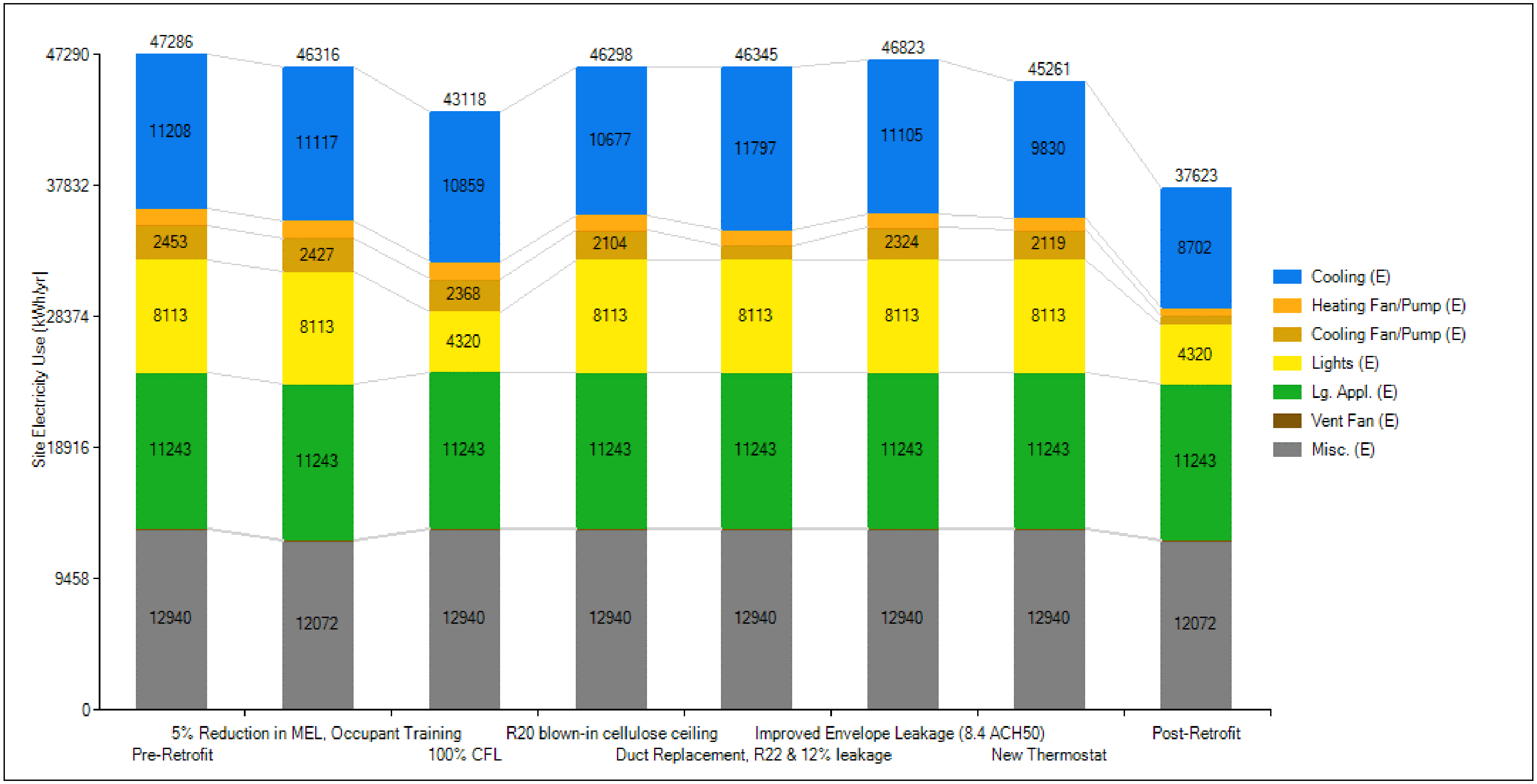
Figure 60 is a series of stacked bars, showing the results of a full-year simulation, for Building 2, in the same fashion as the previous model's results. The total of all the end uses for the Building 2 base case is 394.5 MMBtu/yr, as indicated at the top of the bar. The overall savings when MELs was improved (1.5MMBtu/yr) is similar for the Building 2 model as it was with the previous model's results. Figure 61 shows results from the same single-feature substitution analyses as are plotted in Figure 60, except it reports electricity only (units of kWh/year). The results from Building 2 are given for the whole building (ten 2-bedroom apartments).

Figure 60: Simulated Site Energy Use of Building 2



Source: Electric Power Research Institute

Figure 61: Simulated Site Energy Use of Building 2



Source: Electric Power Research Institute

The Building 2 kWh savings results trends are similar to previous results, despite Building 2 being east-facing. As with the previous models, Table 40 is a numeric chart of the differences in electricity use across end uses for the SFS from Figure 61. The results in Table 40 are for an average per apartment for Building 2.

Table 40: Simulated Kilowatt-hour Savings of Building 2

Site Electricity Savings (Average kWh/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	Post-Retrofit
Misc. (E)	-	87	-	-	-	-	-	87
Vent Fan (E)	-	-	-	-	-	-	-	-
Lg. Appl. (E)	-	-	-	-	-	-	-	-
Lights (E)	-	-	379	-	-	-	-	379
Cooling Fan/Pump (E)	-	3	9	35	142	13	33	188
Heating Fan/Pump (E)	-	(1)	(6)	11	11	23	31	62
Cooling (E)	-	9	35	53	(59)	10	138	251
Total	-	97	417	99	94	46	203	966

Source: Electric Power Research Institute

Figure 62 represents whole-building natural gas budgets. Table 41 shows results from the same analysis, but in units of therms/year.

All the other characteristics for the tabulated results from Table 40 are the same as in the previous model. The results in Table 41 are the tabulated results from the above figure, for an average per apartment for Building 2.

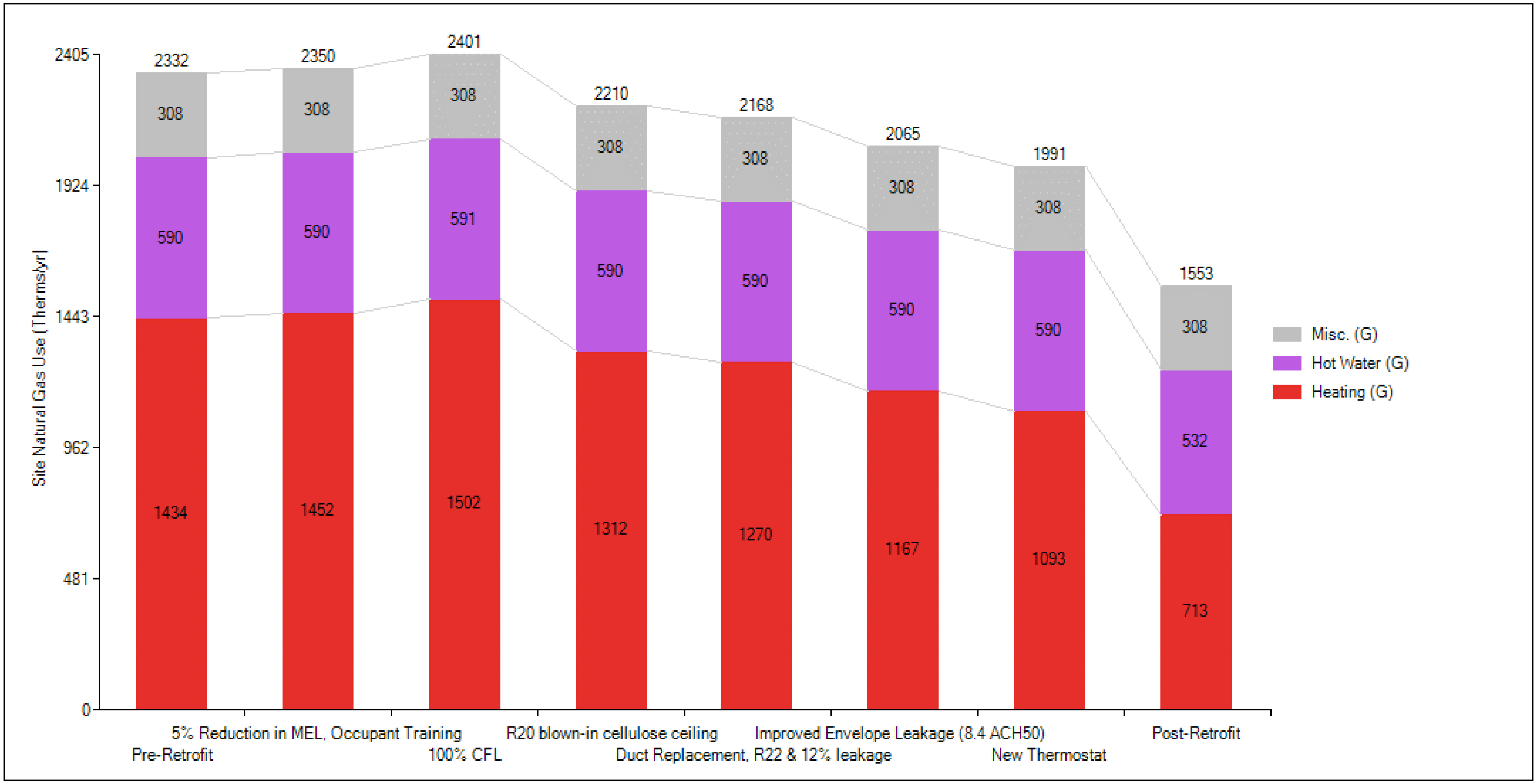
Table 41: Simulated Therms Savings of Building 2

Site Natural Gas Savings (Average Therms/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	Post-Retrofit
Heating (G)	-	(2)	(7)	12	16	27	34	72
Hot Water (G)	-	-	(0)	0	-	0	-	6
Misc. (G)	-	-	-	-	-	-	-	-
Total	-	(2)	(7)	12	16	27	34	78

Source: Electric Power Research Institute

Figure 62: Simulated Therms Use of Building 2



Source: Electric Power Research Institute

The percent savings per each individual EE measure for the Building 2 baseline model, seen below in Table 42, was formatted the same as the previous models, in percent site energy savings (MBtu/MBtu).

Table 42: Simulated Kilowatt-hour Savings of Building 2

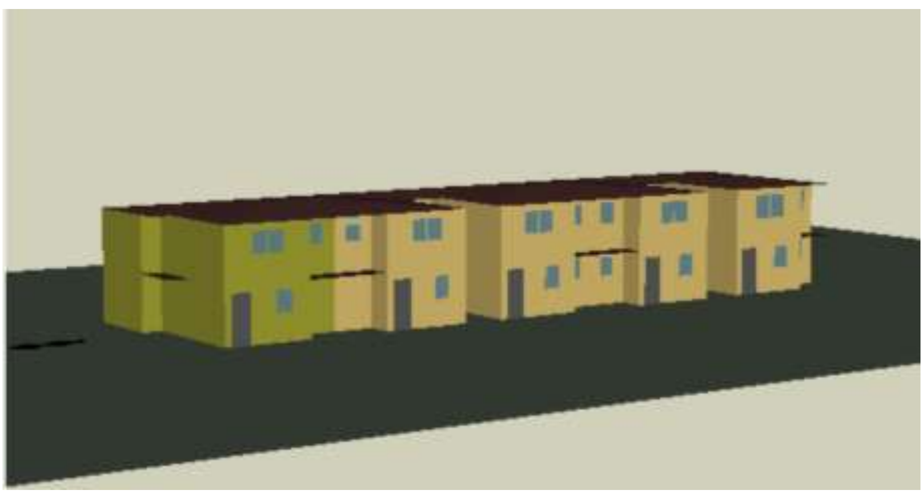
	% Savings
5% Reduction in MEL, Occupant Training	-1%
100% CFL	-3%
R20 Attic blown-in cellulose, ceiling	5%
Duct Replacement, R22 & 12% leakage	7%
Improved Envelope Leakage (8.4 ACH50)	11%
New Thermostat	15%
VER Package	33%

Source: Electric Power Research Institute

Simulation Analysis of Building 3

Building 3 was modeled using the analysis outlined above for the previous two models. A graphical representation of Building 3, generated using BEopt, is shown in Figure 63.

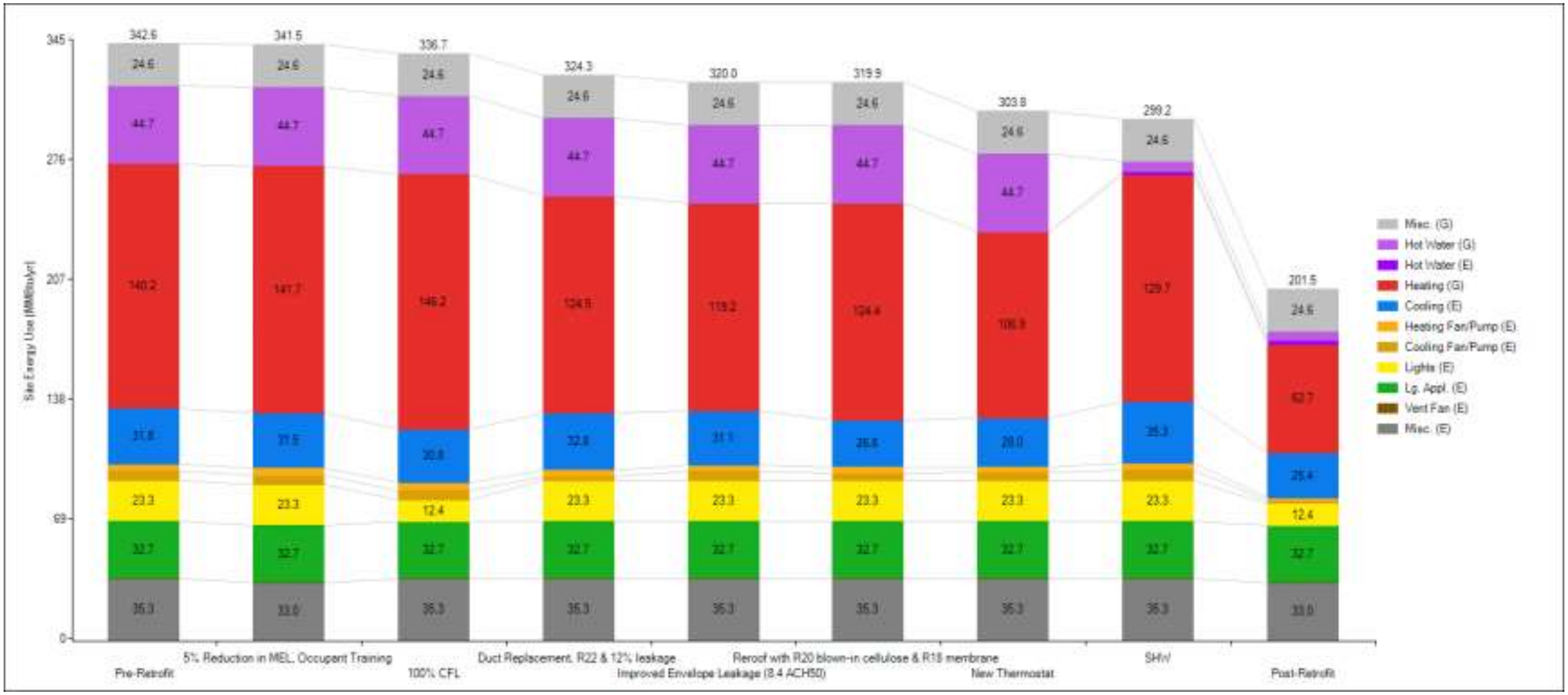
Figure 63: 3D Rendering of Building 3 (unit 19-28)



Source: Electric Power Research Institute

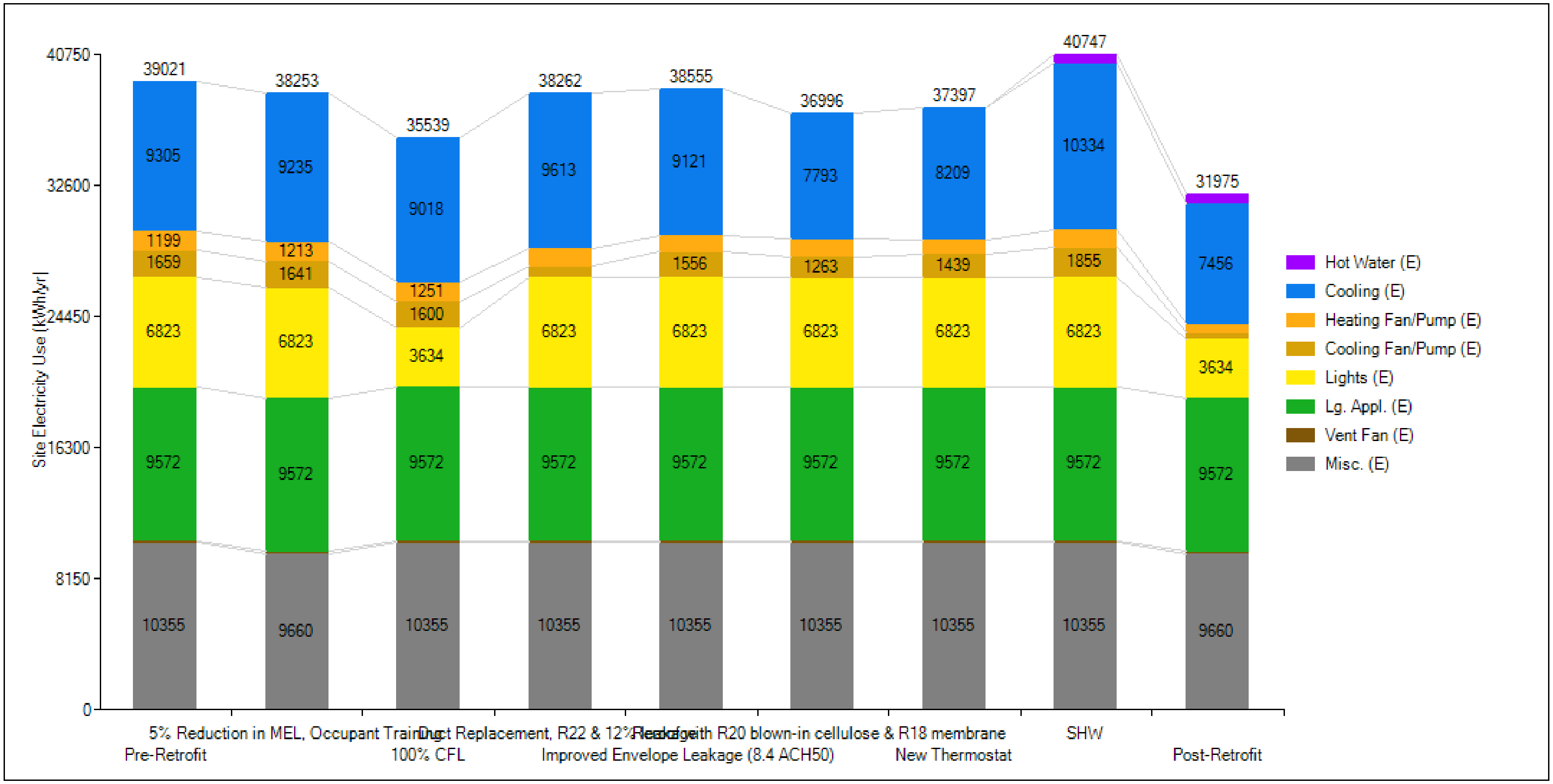
Building 3, unlike the other two buildings, had spray-foam insulation and a protective layer added to the roof, in addition to adding a solar hot water system. The simulation results were then treated in the same manner as the previous two models. The site energy impacts of the individual EE measures on the Building 3 baseline model are shown in Figure 64.

Figure 64: Simulated Site Energy Use of Building 3



Source: Electric Power Research Institute

Figure 65: Simulated Kilowatt-hour Use of Building 3



Source: Electric Power Research Institute

The results for the Building 3 model analysis were treated the same as for the two previous models, except that Building 3 received roof coatings of spray-foam with a protective layer prior to the installation of a solar hot water system on the roof. Building 3 base case is 342.6 MMBtu/yr. Savings from the improvement of the MELs (1.1MMBtu/yr) were similar to the two previous model's results. Figure 65 shows the results from Building 3 in units of kWh/year. The results from Building 3, below, are for the whole building (ten 1-bedroom apartments).

With the exceptions of adding spray-foam insulation and a solar hot water system to Building 3, the other kWh savings results trends are similar to results from two previous models, despite being west-facing and containing 1-Bedroom apartments.

Table 43 summarizes the results from Figure 65. However, Building 3 had the additional retrofits of spray-insulation to the roof (labeled "Reroof" in Table 45) prior to the install of a solar hot water system system on the roof. The results reflect that difference, compared to previous building models. The results in Table 43 are for an average per apartment for Building 3.

Table 43: Simulated Kilowatt-hour Savings of Building 3

Site Electricity Savings (kWh/yr)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	SHW	Post-Retrofit
Misc. (E)	-	695	-	-	-	-	-	-	695
Vent Fan (E)	-	-	-	-	-	-	-	-	-
Lg. Appl. (E)	-	-	-	-	-	-	-	-	-
Lights (E)	-	-	3,189	-	-	-	-	-	3,189
Cooling Fan/Pump (E)	-	18	59	958	103	396	220	(196)	1,240
Heating Fan/Pump (E)	-	(15)	(53)	108	179	117	308	91	659
Cooling (E)	-	70	287	(308)	185	1,512	1,096	(1,029)	1,849
Hot Water (E)	-	-	-	-	-	-	-	(592)	(586)
Total	-	768	3,482	759	466	2,025	1,624	(1,726)	7,046

Source: Electric Power Research Institute

The results from Figure 66 presented in Table 44 are averages per apartment for Building 3. Figure 66 shows results from the Building 3 analysis, also for the whole building, in therms/year.

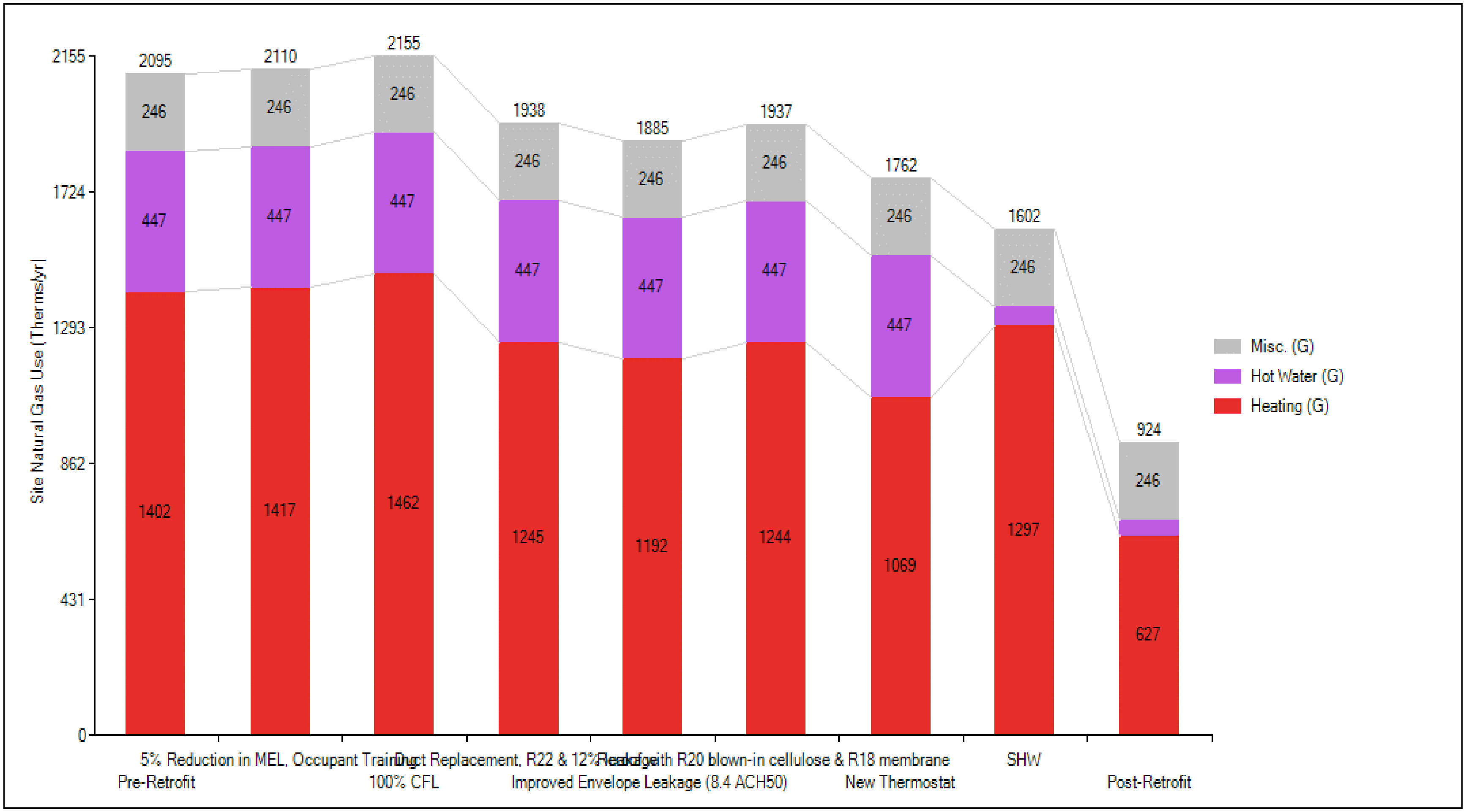
Table 44: Simulated Therms Savings of Building 3

Site Natural Gas Savings (Average Therms/yr per unit)

	Pre-Retrofit	5% Reduction in MEL, Occupant Training	100% CFL	Reroof with blown-in cellulose & R8 membrane	Duct Replacement, R22 & 12% leakage	Improved Envelope Leakage (8.4 ACH50)	New Thermostat	SHW	Post-Retrofit
Heating (G)	0	-1	-6	16	21	16	33	11	78
Hot Water (G)	0	0	0	0	0	0	0	39	40
Misc. (G)	0	0	0	0	0	0	0	0	0
Total	0	-2	-6	16	21	16	33	49	117

Source: Electric Power Research Institute

Figure 66: Simulated Therms Use of Building 3



Source: Electric Power Research Institute

The percent savings per each individual EE measure for the Building 2 baseline model, in percent site energy savings (MBtu/MBtu) is shown in Table 45.

Table 45: Simulated kWh Savings of Building 3

	% Savings
5% Reduction in MEL, Occupant Training	-1%
100% CFL	-3%
Reroof with blown-in cellulose & R8 membrane	7%
Duct Replacement, R22 & 12% leakage	10%
Improved Envelope Leakage (8.4 ACH50)	8%
New Thermostat	16%
Solar Hot Water	24%
VER Package	56%

Source: Electric Power Research Institute

Conclusions of Simulation Analysis

The development of the VERs package for The Village at Beechwood followed a consistent and thorough process to find the optimal retrofit package to suit the buildings and clients. It was the intention of the team to be able to evaluate the packages using monitored data and compare the simulation results to the monitored data. Unfortunately, that proved to be impossible for several reasons, the most important being that it was virtually impossible to evaluate the natural gas savings due to the entire complex being master-metered. No analytical method was found that could manipulate the master-metered gas use to reliably separate the 28 retrofitted apartments from the community-shared uses in the laundry and community center. There were other issues that prevented separation of the electricity savings into their respective end-uses, including data capture and download problems. Nonetheless, conclusions can be drawn from the simulation results that were generated by team members with extensive experience in modeling, simulating and calibrating such results.

Aside from adding solar hot water or roof insulation, for all three Building model analyses, the two most effective features were reducing the building envelope leakage to 8.4 ACH_{50} and adding a programmable thermostat. The VERs package was predicted to save about 30 percent of the total, per-unit energy use, and with the addition of spray-foam insulation to the roof and installation of a solar hot water system, the savings were predicted to save more than 50 percent. However, the actual savings were less than predicted.

Based on the depth of experience of the team and discussions within the team, they believe that the expected savings from the thermostats likely suffered from changes in thermostat settings pre- and post-retrofit due to take-back, allowing the tenants to afford to set their thermostats to be more comfortable and use more energy in the process. To achieve savings from smart, connected thermostats, they need to be connected to master controllers and have regulated settings. Such oversight would require culture changes and may not be feasible in the near term.

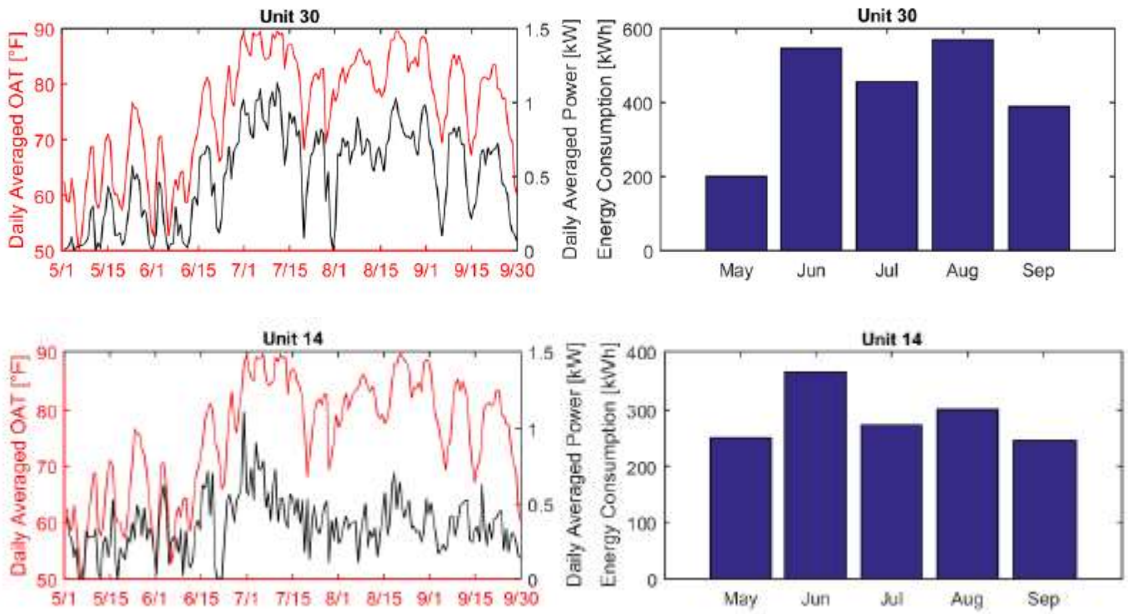
The savings from reduced envelope leakage and the community hot water retrofit, including the solar hot water, and new storage and distribution components were achieved, but at a high cost for the hot water retrofits, particularly the new distribution system. The duct savings were achieved in the two pilot retrofits, but similar savings were not achieved in some or most of the other apartments. This was likely due to expectations that the high quality work achieved in the pilots would also be achieved in the standard retrofits were not met due to the typical construction push to get the job done quickly, exacerbated by the difficulties inherent in having expert quality assurance present throughout the retrofit process, including the relatively remote location of the community. The duct retrofit also required asbestos abatement that made its costs too high to realistically recover within any current financing period. More research is required to find simpler, more practical VERs that may have lower energy savings goals, but that, if they can be cost-effective and if financing problems can be solved, could be performed much more broadly, producing greater total energy savings.

Second Stage: Initial Analysis of Envelope Improvement

This second stage of analysis focused on the AC units energy use of each retrofitted household before and after the retrofit in 2015, as well as the comparison between retrofitted household and the control group or baseline. Most of the retrofits were implemented during June and July of 2015. The collected data showed that the AC unit energy use of some apartments was more weather-driven, meaning the cooling load followed the pattern of outside air temperature. However, the electric energy use of some apartments was less correlated with the weather, which could have been caused by many reasons, such as the apartments were vacant or less frequently occupied during the day, or the occupants compromised thermal comfort to save electricity. Thus, only the weather-driven electric energy patterns from the retrofitted group (apartments 1-28) and the control group (apartments 29-38) were selected to compare the energy performance at this stage of data analysis. Apartment 30 was selected as an example of baseline and apartment 14 was selected as the retrofitted group.

In Figure 67, the time-series graph on the left-hand side compares the daily average outside air temperature and the AC unit's averaged power consumption of the day). The energy consumption of both apartments was weather-driven and the team observed a consistent energy pattern in apartment 30 (as a baseline) but a gradually reduced pattern of apartment 14 due to the energy efficiency retrofit implemented in June and July timeframe. On the right-hand side below, one can see the monthly energy use of the AC units. Relative to apartment 30, in July and August, the electric use for cooling in apartment 14 dropped quite substantially.

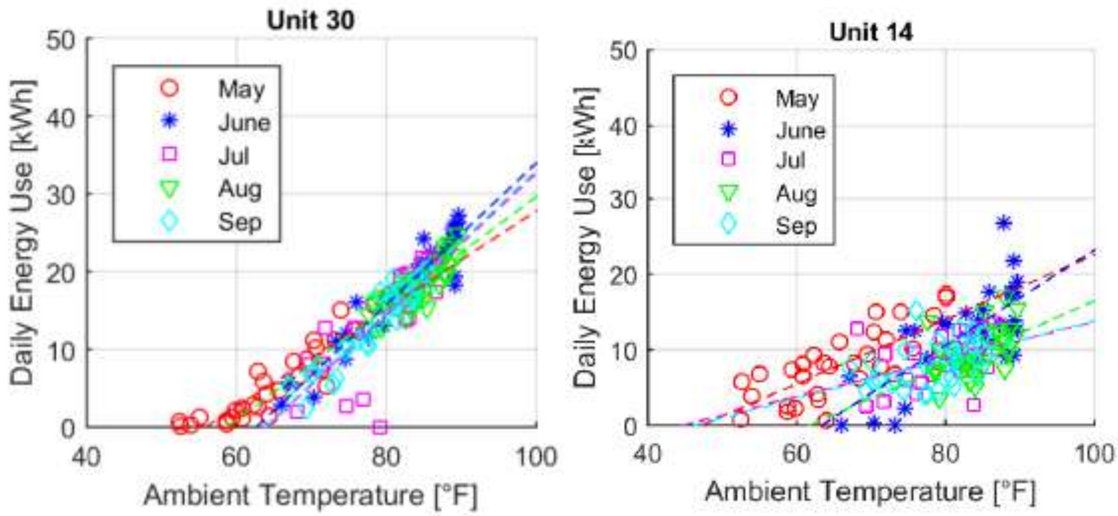
Figure 67: Envelope Improvement of a Unit in Control Group Unit versus Baseline



Source: Electric Power Research Institute

To better understand the change of the household's thermal characteristics after the implementation of duct sealing and insulation, the research team conducted further analysis using the AC unit's daily energy use (kWh) and the averaged outside air temperature. As shown in the scatter plot, the team first plotted each day's outside air temperature and the AC unit's energy use (that is, one dot represents one day), and color noted the dots for each month. Linear regression lines based on the dots of each month were done. The team observed apartment 30 has a consistent energy consumption pattern throughout the observed months as the regression lines have similar slopes and even intercepts in this case; whereas, apartment 14's energy consumption patterns were changed due to the retrofit implemented (Figure 68). For apartment 14, it was observed the slope of the regression lines of May and June are higher than that of July, August and September, meaning the retrofit has changed the apartment's thermal characteristics and the energy use in apartment 14 was more efficient in July, August and September. Thus, the second stage of analysis shows the envelope improvement had made a difference to the thermal characteristics of apartments and improved the energy efficiency.

Figure 68: Thermal Characteristic Analysis of Control Group versus Treatment Group



Source: Electric Power Research Institute

Third Stage: Pre- and Post- Retrofit Analysis of Apartment Units

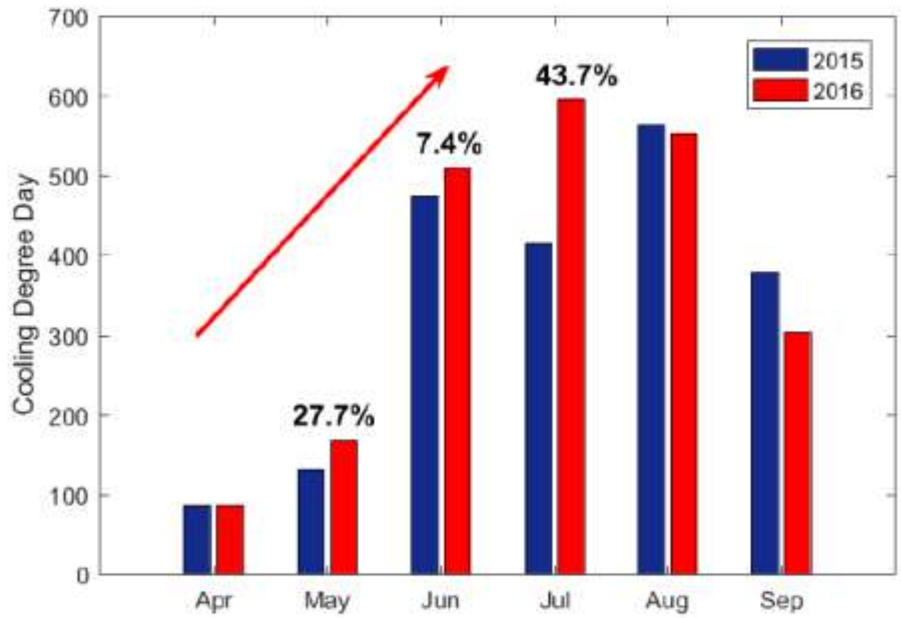
Electric Data Analysis

The team conducted the third stage of data analysis after most of data was collected in October 2016 to compare the energy use of pre- and post- retrofits of the 30 apartments, and compare the energy use of the treatment and control groups.

The first thing the research team noticed was that 2016 was much warmer than 2015 – the cooling degree day was 27.7 percent, 7.4 percent, and 43.7 percent more in May, June and July, respectively, as shown in Figure 69. Thus, the energy use of the retrofitted group actually increased in 2016 if directly compared with the data of 2015.

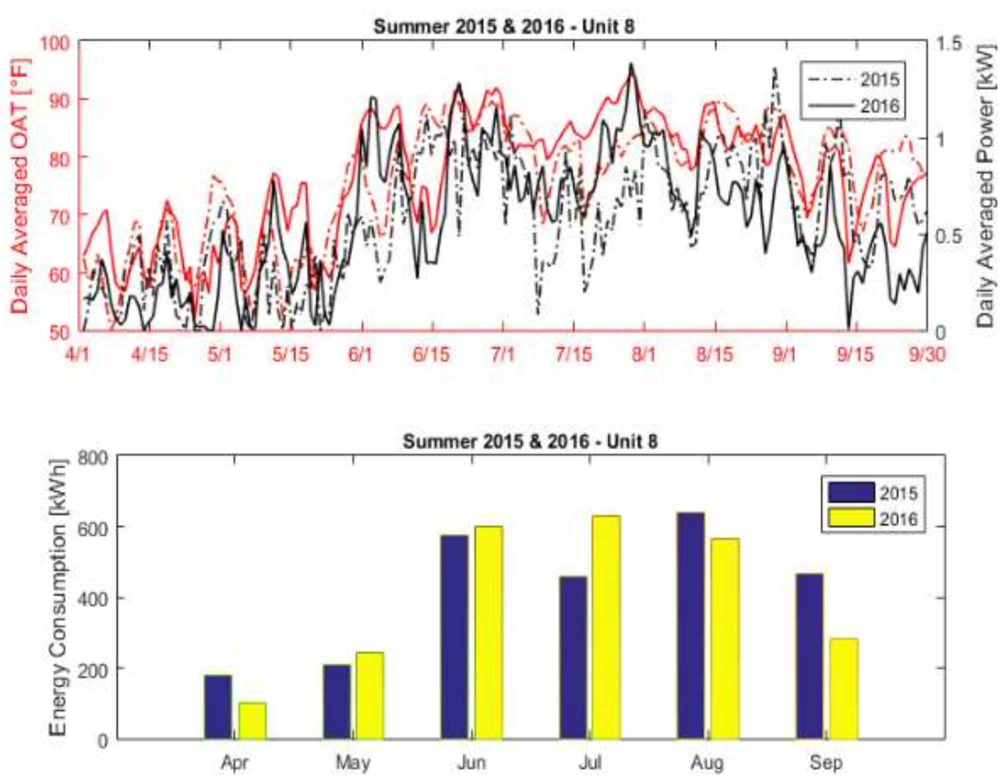
Figure 70 shows that the hotter summer in 2016 increased the energy use of AC units for cooling and resulted in more energy use in May, June, and July. Given the results, the team investigated the following questions: how was the energy performance of the control group compared to the treatment group? Figure 71 shows that the energy use in one of the control group also increased along with the patterns of the hotter summer months. The team could observe that the energy use differences are greater in the control group than in the treatment group. The research team found that some occupants had difficulties scheduling the smart thermostats after installation. This was partly due to the user-interface, but also because the occupants changed frequently over the course of project. The research team conducted further analysis to understand the energy use in both cooling and heating seasons on all apartments, and further, the impacts from the thermostat brands on energy use.

Figure 69: Cooling Degree Day Comparison of Summer 2015 and 2016



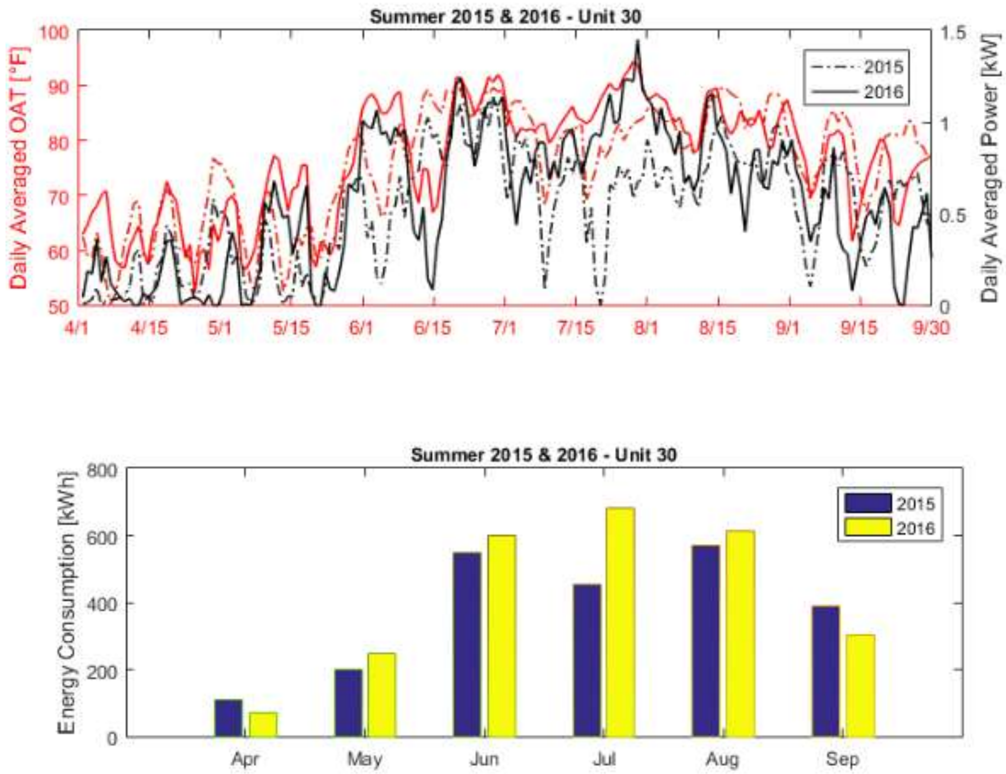
Source: Electric Power Research Institute

Figure 70: Electric Energy Consumption of One of the Rooftop Units in Treatment Group



Source: Electric Power Research Institute

Figure 71: Electric Energy Consumption of One of the Rooftop Units in Control Group

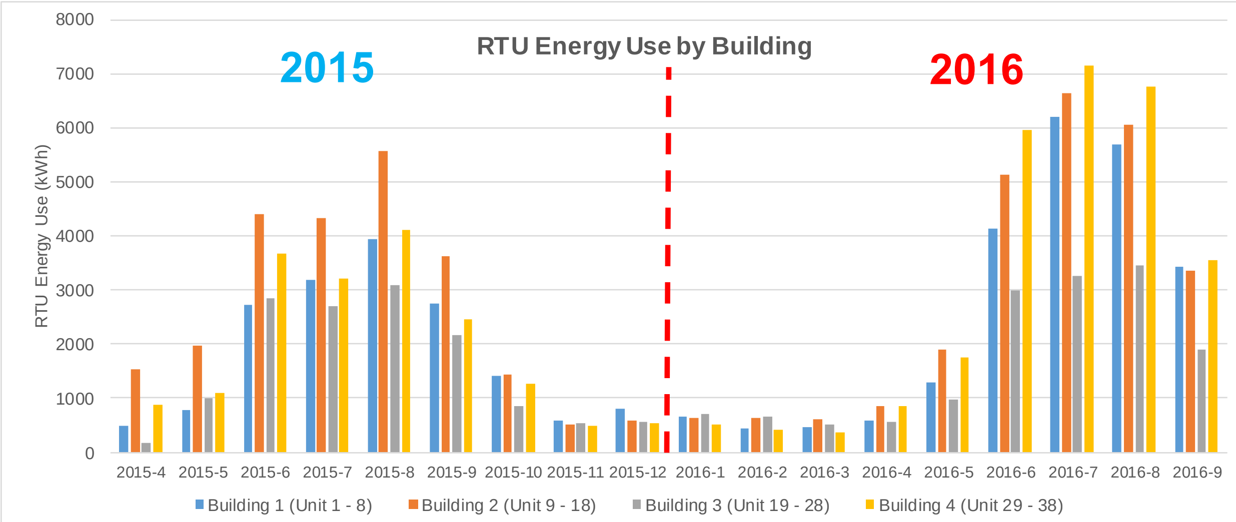


Source: Electric Power Research Institute

In Figure 72, the electric energy use of the RTU is plotted from the time the data monitoring system was setup in April 2015. The energy use includes both the AC compressor and the ventilation fans, reflecting both winter and summer ventilation load, plus the summer cooling loads. The weather data of Lancaster indicate the summer season is around six months, from April to September, with the other six months considered to be winter months. April 2015 to December 2015 (that is, six months of summer and three months of winter) are compared against January 2016 to September 2016 (that is, six months of summer and three months of winter) for both heating and cooling seasons.

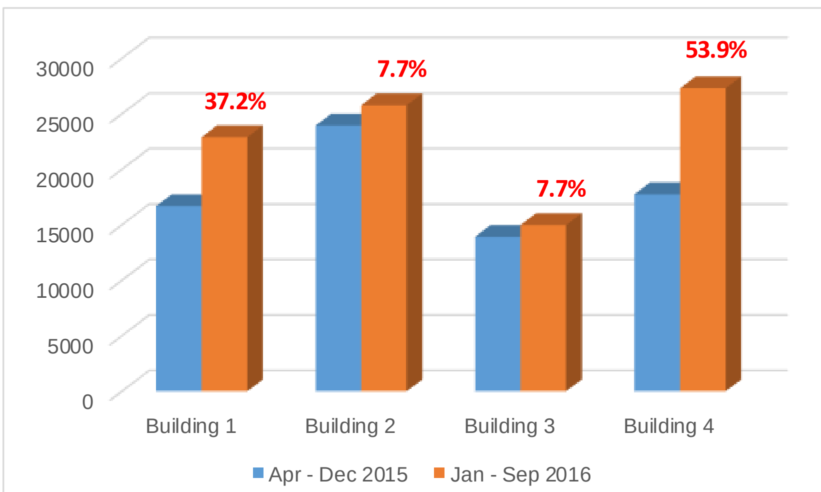
Referring to Figure 73 the treatment group: Building 1, 2 and 3 all consumed more cooling energy and ventilation in 2016 than in 2015. Specifically, building 1 (apartment 1–8) consumed 37.2 percent more; Building 2 (apartments 9–18) consumed 7.7 percent more; and Building 3 (apartments 19–28) consumed 7.7 percent more. The control group Building 4 (apartments 29–38) also consumed more cooling and ventilation energy in the AC units, which was 53.9 percent more due to the hotter summer of 2016.

Figure 72: Monthly Electric Energy Use of Rooftop Units of Building 1-4 in 2015 and 2016



Source: Electric Power Research Institute

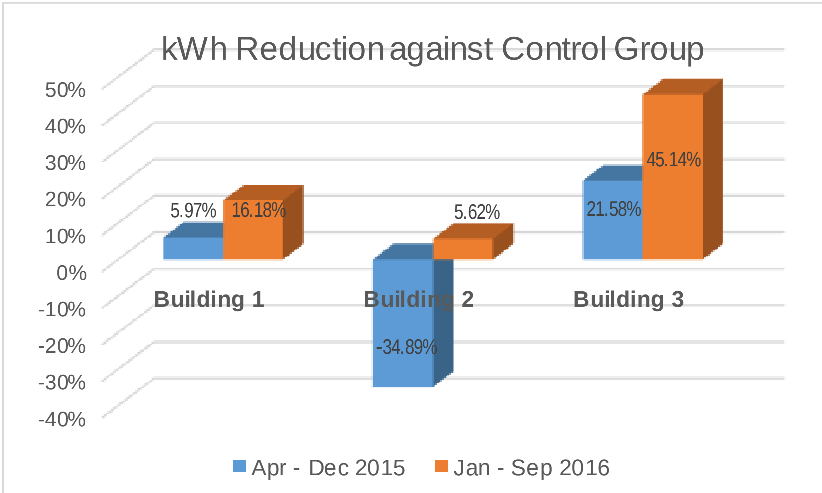
Figure 73: Comparison of Electric Energy Use of Rooftop Units Between 2015 and 2016



Source: Electric Power Research Institute

Thus, the research team conducted further comparison to compare the "difference of differences" – the comparison of energy use reductions between the treatment group and control group of 2015 and 2016 (Figure 74). Building 1 (apartments 1–8) consumed 5.97 percent less energy than the control group in 2015 and consumed 16.18 percent less than the control group in 2016 – a 10.21 percent improvement in 2016. Building 2 (apartments 9–18) consumed 34.89 percent more energy than the control group in 2015 and consumed 5.62 percent less energy than the control group in 2016 – a 40.51 percent improvement in 2016. Building 3 (apartments 19–28) consumed 21.58 percent less energy than the control group in 2015 and consumed 45.14 percent less energy than the control group in 2016 – a 23.56 percent improvement in 2016. The research team believes the analysis on the building level averages out the behavior driven factors and the "difference of differences" analysis indicates the energy efficiency improvements because of the VER package implemented in Building 1, 2 and 3.

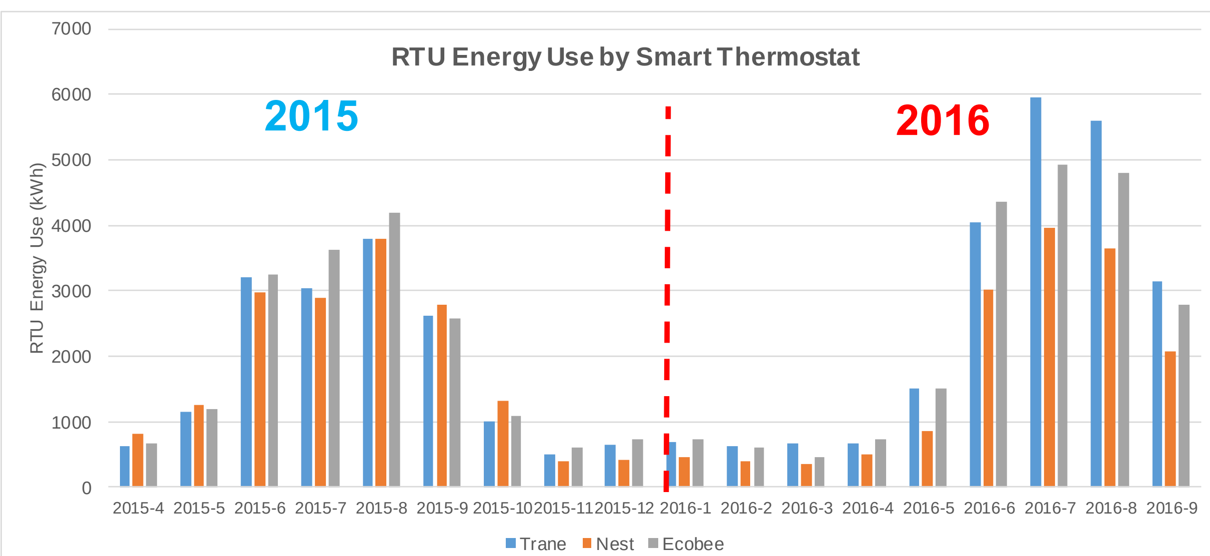
Figure 74: Comparison of the Energy Use Reductions between Treatment and Control



Source: Electric Power Research Institute

This project installed smart thermostats for home energy management in the control group and also tested the effectiveness between product manufacturers. The project installed Ecobee, Trane Nexia, and Nest Thermostats in the apartments (10 of each brand) and the research team conducted further analysis to compare the energy use of AC units controlled under those three thermostat products. The monthly energy use covered 9 months (6 months of summer and 3 months of winter) in 2015 and 2016 to compare the ventilation loads and cooling loads that were controlled by the three brands of thermostats (Figure 75).

Figure 75: Monthly Electric Energy Use of Rooftop Units Controlled by Smart Thermostats

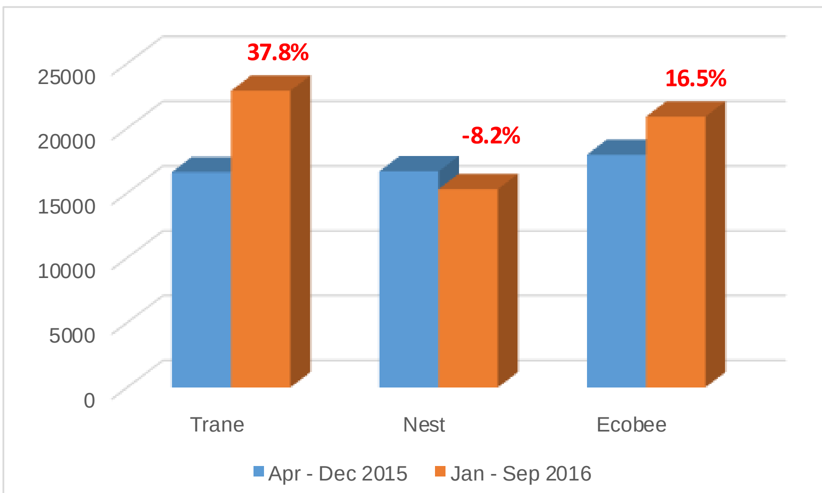


Source: Electric Power Research Institute

Not all thermostat groups consumed more energy as a result of the much hotter weather of 2016 The Trane Nexia thermostats group and Ecobee thermostats group consumed more energy in 2016 but the Nest thermostat group reduced the energy consumption in 2016 compared to that of 2015. Specifically, the Trane Nexia thermostat group (apartments 1, 5, 6, 9, 15, 16, 20, 24, 25, 28) consumed 37.8 percent more; the Nest thermostat group (apartments 2, 8, 11, 12, 14, 18, 19, 23, 27, 83) consumed 8.2 percent less; and the Ecobee thermostat group (apartments 3, 4, 7, 10, 13, 17, 21, 22, 26, 84) consumed 16.5 percent more.

Since the energy use of the groups were observed as both increased and decreased among those groups, the research team again conducted a "difference of differences" analysis to compare with the control group to draw a conclusion on the performance of these thermostat brands.

Figure 76: Comparison of Electric Energy Usage of Rooftop Units Controlled by Three Different Thermostat Brands

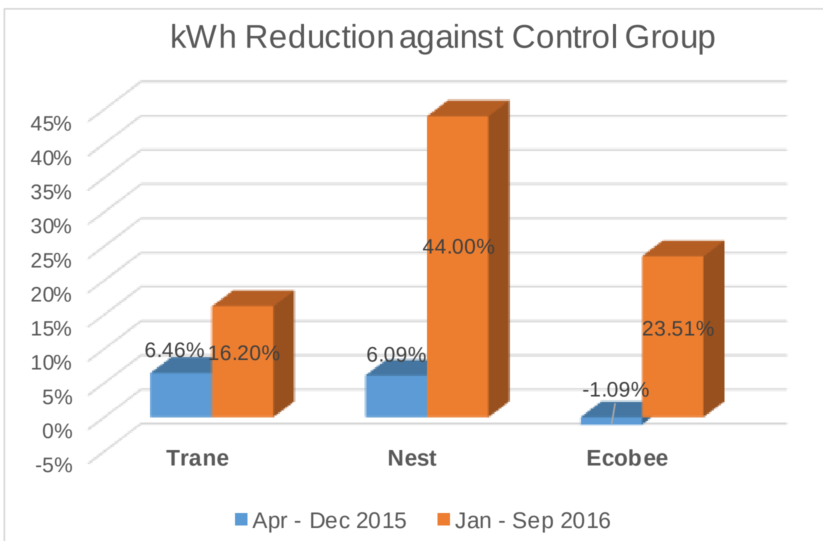


Source: Electric Power Research Institute

The Trane Nexia thermostat group (apartments 1, 5, 6, 9, 15, 16, 20, 24, 25, 28) consumed 6.46 percent less than the control group in 2015 and 16.2 percent less in 2016 – a 9.74 percent improvement in 2016 (Figure 77). The Nest thermostat group (apartments 2, 8, 11, 12, 14, 18, 19, 23, 27, 83) consumed 6.09 percent less than the control group in 2015 and 44 percent less in 2016 – 37.91 percent improvement in 2016. The Ecobee thermostat group (apartments 3, 4, 7, 10, 13, 17, 21, 22, 26, 84) consumed 1.09 percent more in 2015 and 23.51 percent less in 2016 – a 24.6 percent improvement in 2016. The results show that the smart thermostats did further improve the energy efficiency improvement on top of the VER packages installed on site and Nest thermostats seem to be able to drive up more savings. Only ten apartments for each thermostat brand is still a too small sample size to draw any conclusions on the capabilities, but the analysis still provided some insights on the energy efficiency potential of the HEMS installed in those buildings.

Historically, smart thermostats have encountered some difficulties in penetrating into the low-income multifamily neighborhood. However, the research team received some very positive feedback on the smart thermostats, and the tenants were using the thermostats to set up their heating and cooling schedules. One tenant expressed her satisfaction with the smart thermostats installed in the apartment during a routine checkup and showed the research team and the maintenance group the weekday/weekend schedules that she set up on the thermostat control panel and the setup page on her smartphone. The research team also found other tenants who did not care about the new technology and operated the smart thermostats as on/off control – simply shut off the thermostats when they were not at home or the thermal comfort level was reached. This group of tenants preferred the simple control of traditional thermostats. Their indoor air temperature/humidity and energy use were observed to be similar to those of the control group.

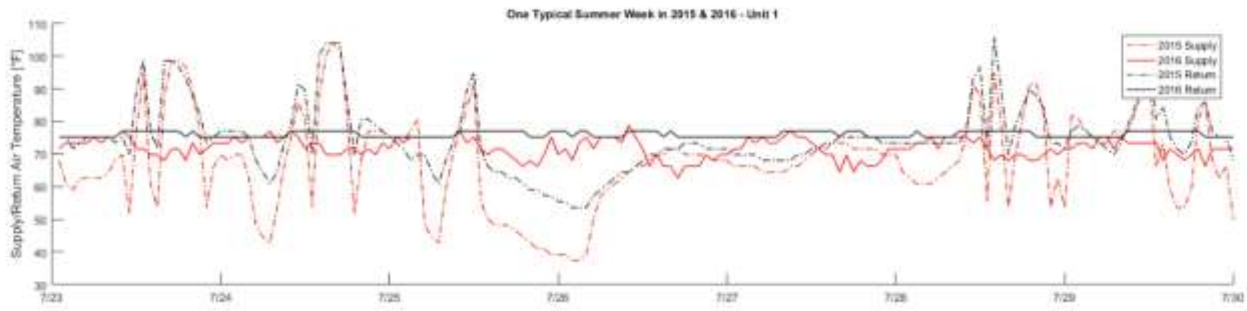
Figure 77: Comparison of Electric Energy Reduction of Rooftop Units Between Treatment and Control as Controlled by Different Thermostat Brands



Source: Electric Power Research Institute

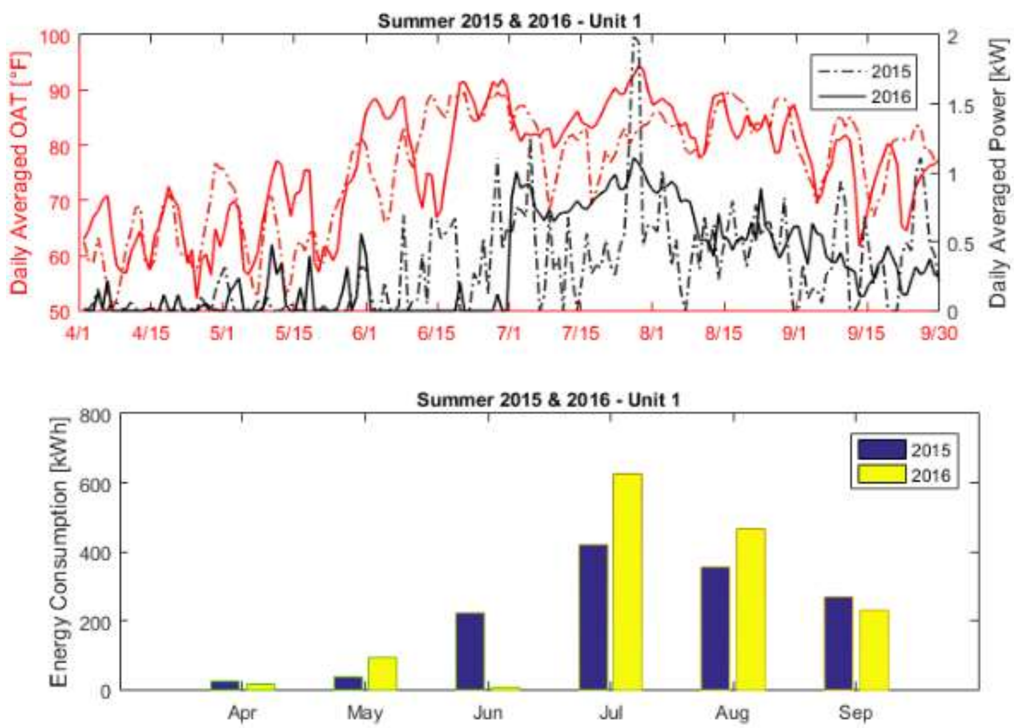
The research team found the energy use in the apartments was so driven by behavior that even if apartments were equipped with the same VER packages and the same thermostat, the energy use still could be greatly different (Figure 78). The research team compared apartment 1 and apartment 9, which had Trane Nexia thermostats installed for this study. Referring to Figure 79, the occupant in apartment 1 kept the smart thermostat on during the one week observed, thus the supply and return air temperature patterns were steadier than those of 2015 when the HVAC load was controlled by a traditional thermostat (Figure 80).

Figure 78: Supply and Return Air Temperature of One Typical Summer Week Comparison



Source: Electric Power Research Institute

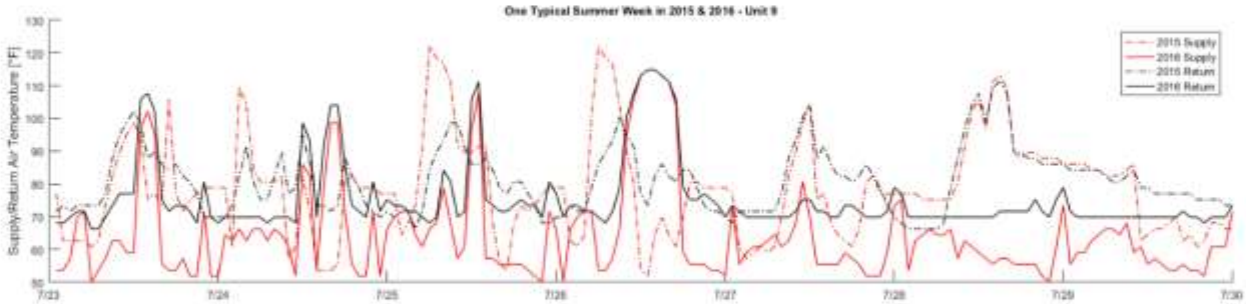
Figure 79: Electric Energy Consumption of the Rooftop Units on Apartment Unit 1



Source: Electric Power Research Institute

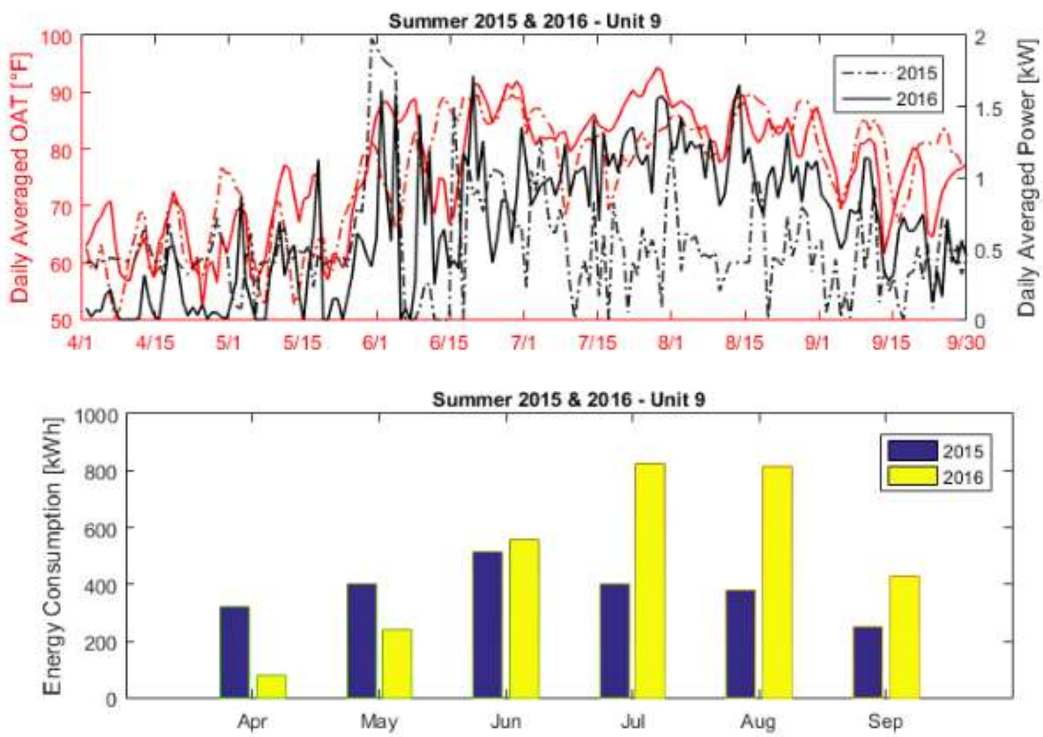
Figure 81 shows that the occupant in apartment 9 operated the smart thermostat as an on/off device, so that the supply and return air temperature patterns were still similar to those of 2015 – the supply and return air temperature could go up to 120 ˚F when the thermostat was turned off. The different occupant behavior resulted in a completely different energy use pattern of the rooftop units, which is also reflected to the monthly energy use kWh. Therefore, even if buildings and apartments are carefully to be energy efficient, the energy use is still dependent on how the occupants use the thermostats and other loads. Thus, one of the lessons learned from this project is that a near-ZNE apartment does not necessarily mean a near-zero utility bill – behavior is important.

Figure 80: Supply and Return Air Temperature of One Typical Summer Week Comparison



Source: Electric Power Research Institute

Figure 81: Electric Energy Consumption of the Rooftop Units on Apartment Unit 9



Source: Electric Power Research Institute

Natural Gas Data Analysis

Due to the high cost of sub-metering of natural gas use, the gas consumption of the rooftop units were only monitored in a few selected apartments – 8 units in the treatment group and 15 units in the control group, listed in Table 46. Based on the energy efficiency improvements of the electric energy use data, the research team expected to see an impact on the gas use, primarily because of the envelope improvement. However, occupant behavior and the high turn-over rate of the community also needed to be considered.

Table 46: Monitored Natural Gas Use of Treatment Group and Control Group

Retrofit														
Unit 7	Unit 6	Unit 9	Unit 13	Unit 18	Unit 19	Unit 25	Unit 26							
Baseline														
Unit 29	Unit 37	Unit 35	Unit 43	Unit 44	Unit 45	Unit 71	Unit 72	Unit 81	Unit 82	Unit 85	Unit 86	Unit 97	Unit 98	Com Area

Source: Electric Power Research Institute

Space heating, water heating and cooking are the gas-using end uses, with space heating the largest component of consumption in apartments. Gas consumption for space heating is dependent on how the occupants are using the thermostats to achieve comfort and convenience. Assuming the tenant's behavior does not change (that is, no change-over of tenants or no meaningful change of energy use behavior in an apartment in 2015 and 2016), improvement of the building's envelope should be reflected in reduced gas use for heating the building. The apartment building's envelope (walls, roofs, floors, windows, and doors) has an important impact on heating energy use. The energy efficiency of the building envelope can be characterized by a factor called building load coefficient, which is defined to account for all the above-grade building envelope components to characterize the total heat transmission of the building.

When the envelope is improved by insulation in walls and roof and duct sealing, the building load coefficient factor is reduced, assuming no changes in the indoor air temperature set point or in the internal heat gains within the household. That is, it can be considered as a lumped U-value of the apartment that counts for the effects of transmission and infiltration losses across the building envelope, per degree temperature difference of indoor and outdoor per unit floor area, in Btu/hr/°F/square foot. The typical way of analyzing natural gas use for space heating is to separate natural gas use data by heating and non-heating season season (based on the definition of summer and winter months used in this report), then scatter the natural gas use data and the associated outdoor air temperature recordings (Figure 82). The intersecting point of the trendlines of the heating and non-heating seasons yields the balance temperature point of the building, T_b.

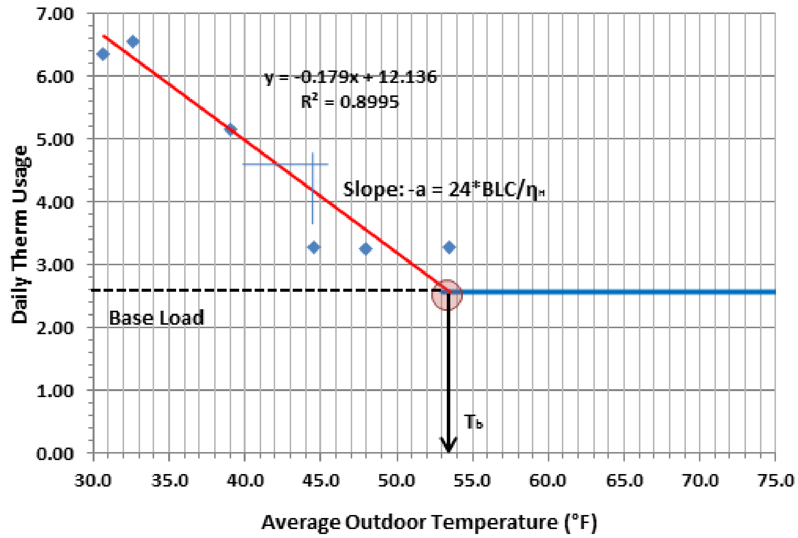
It can be calculated as the following:

- $T_{thermostat}$ is the thermostat temperature set point
- $\dot{Q}_{sol}$ is the net heat gain due to solar radiation
- $\dot{Q}_{int\ gain}$ are the internal gains due to people, lights and appliances
- $\dot{Q}_{ground}$ is the ground heat loss if the apartment is on the first/ground floor
- BLC is the Building Load Coefficient

The equation shows that the intersecting point, T_b, is independent of weather and is usually used as an indicator to reflect the change of building load coefficient due to envelope improvement, assuming no major behavior changes, but also dependent on large amount of data.

$$T_b = T_{thermostat} - \frac{\dot{Q}_{sol} + \dot{Q}_{int\ gain} - \dot{Q}_{ground}}{BLC}$$

Figure 82: Scatter of Natural Gas Use Data and Outdoor Temperature Data to Find Tb



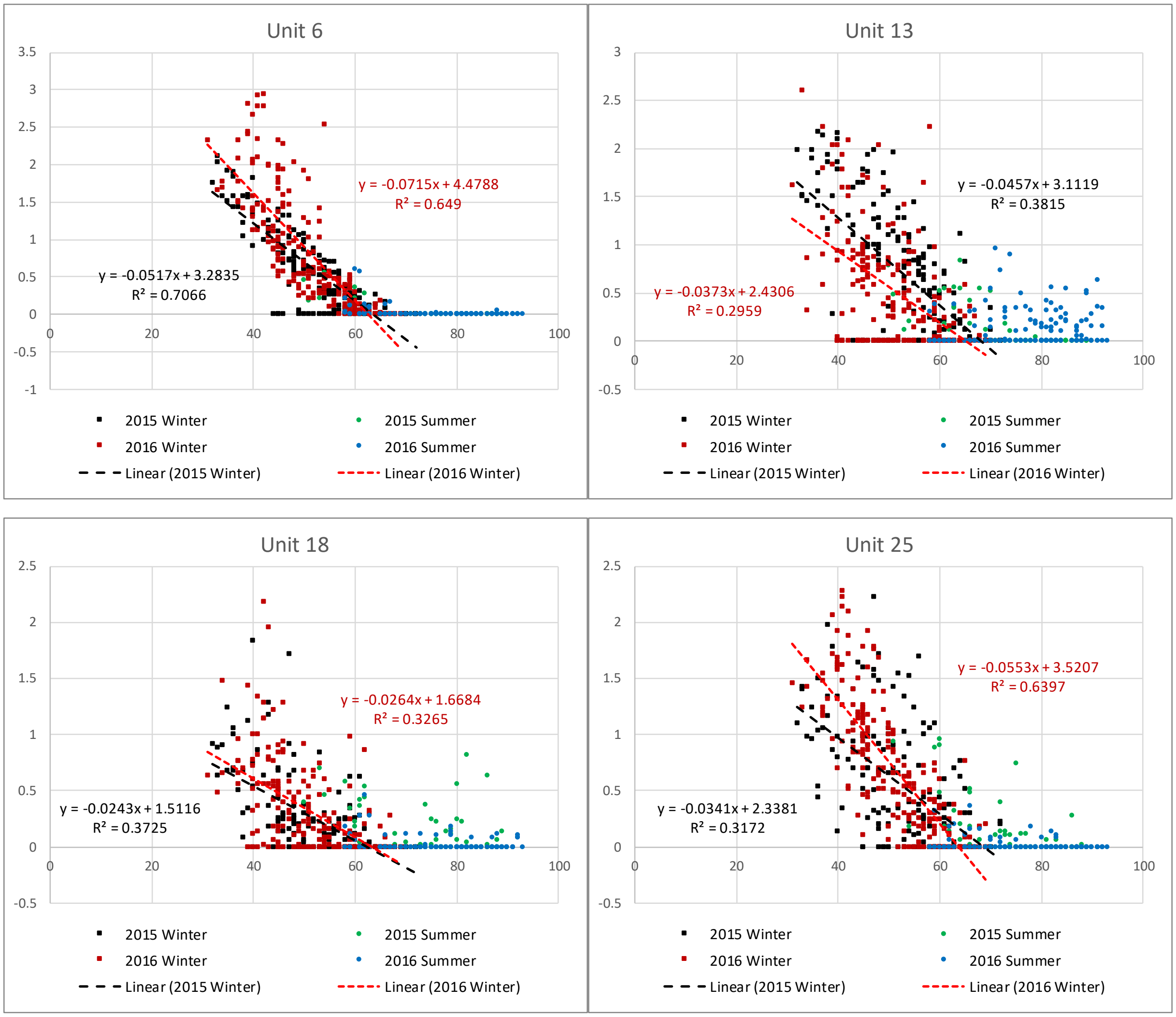
Source: Electric Power Research Institute

Typically, behavior studies need a large number of samples to point to a conclusion. The data from apartments that are more likely occupied during the time of monitoring are compared with treatment and control groups, to facilitate a comparative or side-by-side analysis on an individual apartment level, with the electric data provided.

The team observed that the natural gas use patterns of the apartments were highly behavior-driven, depending on the occupant's individual preferences and lifestyle. Given the limited data set, the analysis focused on investigating whether the collected data show any tendency of thermal characteristics improvement or changes between the treatment group and the control group. As discussed earlier, the balance temperature point of the building, T_b, should be reduced with an improved building envelope (that is, a smaller building load coefficient), assuming the internal heat gains, occupant behavior and thermostat temperature set points do not change before and after the retrofits.

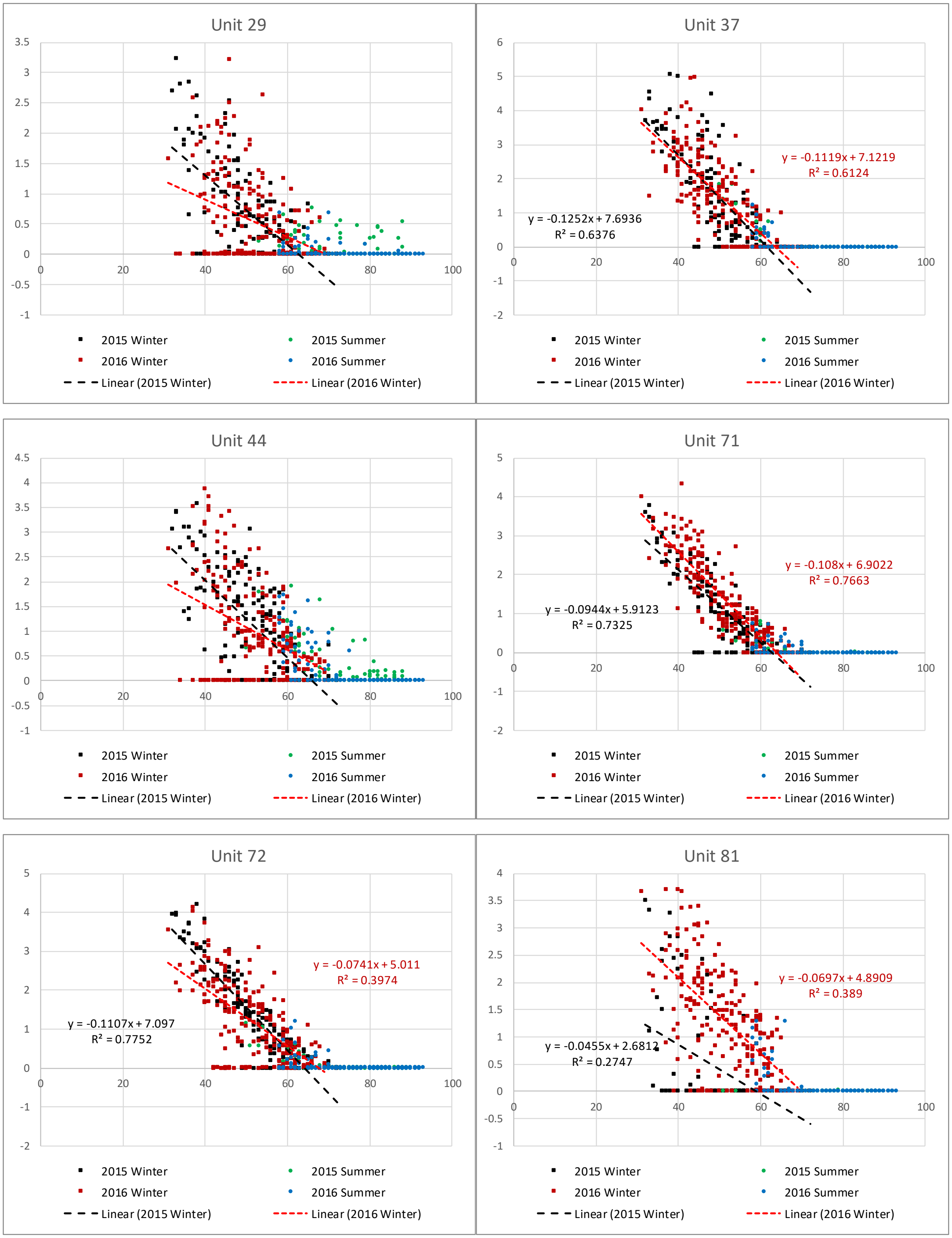
Figure 83 shows the scatter of natural gas use (in 100 cubic feet units, on Y-axis) correlated with the outside air temperature (in degrees Farenheit, on X-axis). Graphs of units 6, 13, 18, 25, which were given the VER, show that the 2016 data, post-retrofit, is intersecting a balance temperature point smaller than that of 2015 data, pre-retrofit. The control group, shown in Figure 84, does not show a reduction in balance point temperature. Because this observation is based on the data from a limited sample of apartments, the research team selected the data points of all the apartments to compare with the treatment group, to help average out the behavior and occupancy factors.

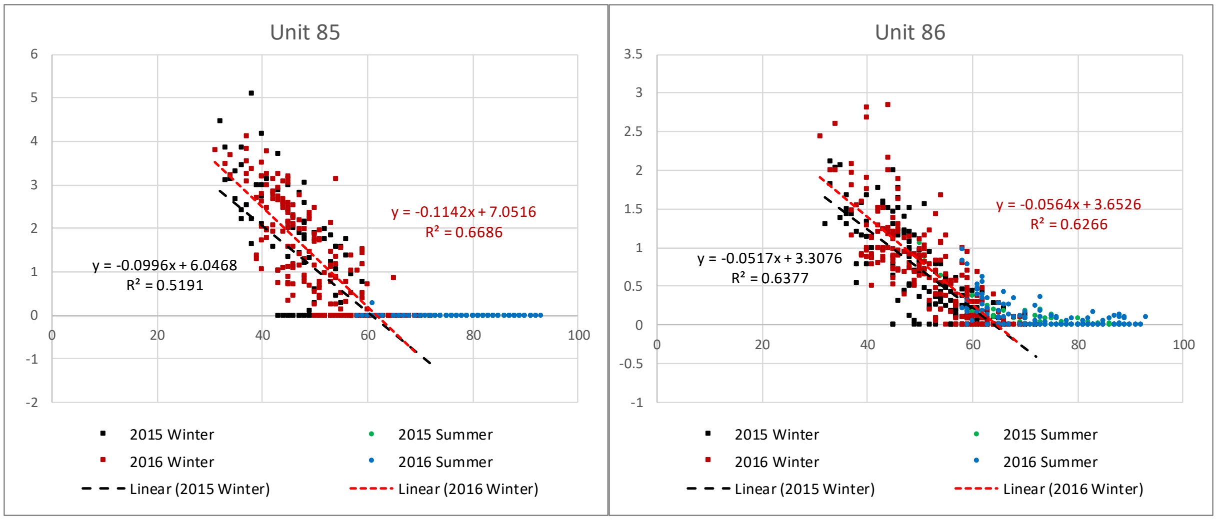
Figure 83: Scatter of Natural Gas Use vs. Outside Air Temperature (Treatment Group – Unit 6, 13, 18, 25)



Source: Electric Power Research Institute

Figure 84: Scatter of Natural Gas Use vs. Outside Air Temperature
(Control Group – Unit 29, 37, 44, 71, 72, 81, 82, 85, 86)

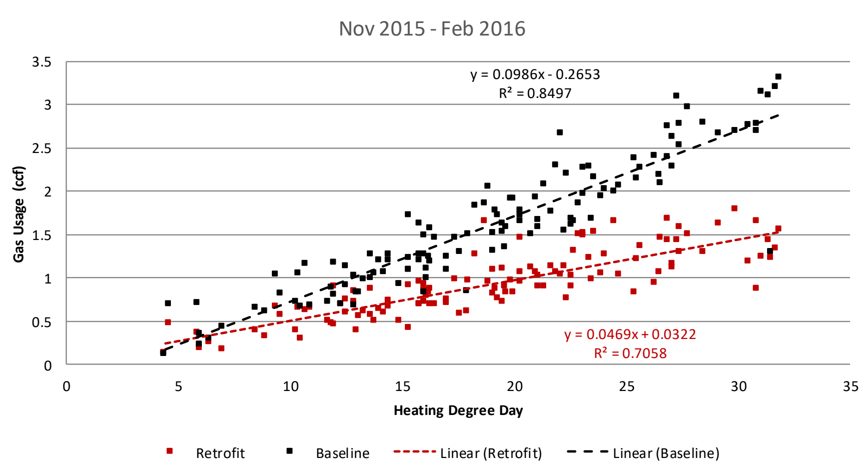




Source: Electric Power Research Institute

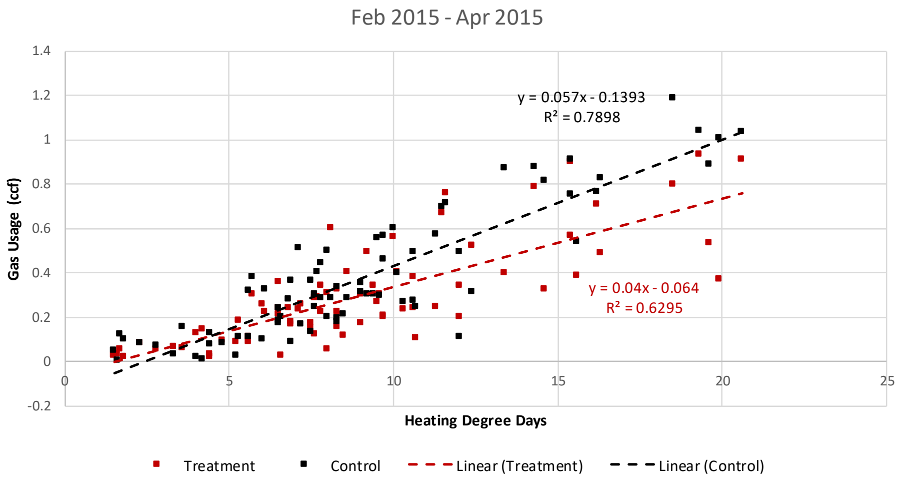
Figure 85 shows the scatter of the averaged natural gas use in units of 100 cubic feet (ccf) versus heating degree-days of the monitored apartments in the treatment group (red dots) and control group (black dots) from November 2015 to February 2016. Figure 86 shows the same information from February to April, 2015. The gas use monitoring system started to collect data from Late January of 2015, thus the monitored winter period of February 2015 to April 2015 covers 77 non-zero consumption days, and the monitored winter period of November 2015 to February 2016 covered 121 non-zero consumption days. The data show that the monitoring period of 2015-2016 was colder than the period of 2014-2015. Even though gas use tended to increase in all apartments from the pre-treatment period to the post-treatment period, it increased less in the treated apartments than in the control apartments, on average. This shows the confounding effect of changing weather on energy usage, largely compensated for by normalizing by degree-days, though precipitation and cloud cover can also have substantial effects. Changing occupancy can also throw off usage either way, which is why a large sample size is needed to normalize data.

Figure 85: Scatter of Natural Gas Use and Outside Air Temperature (Nov 2015-Feb 2016)



Source: Electric Power Research Institute

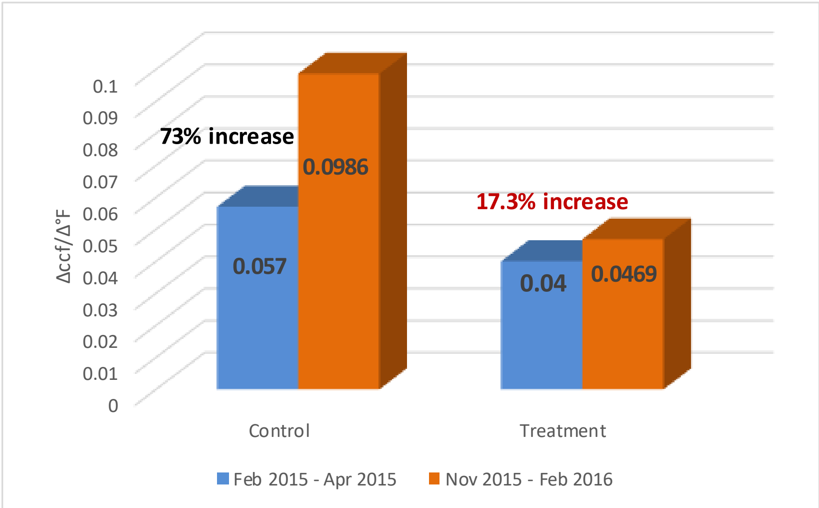
Figure 86: Scatter of Natural Gas Use and Outside Air Temperature (Feb 2015-Apr 2015)



Source: Electric Power Research Institute

The slope of the linear regression trendlines indicates the increase of natural gas use (in ccf – centum cubic feet or 100 cubic-feet) per ˚F decrease of outside air temperature. Figure 87 compares the slopes of the treatment group and control group in those two monitored winter periods. It shows the control group had to increase about 73 percent of gas use because of the much colder winter of 2015-2016, but the treatment group only had to increase 17.3 percent of gas use – about 57 percent improvement of gas use efficiency on average. Thus, the analysis based on the average of all monitored apartments shows the improvement of gas use efficiency after the installation of the VER packages.

Figure 87: Gas Consumption Increase per °F Decrease of Outside Air Temperature



Source: Electric Power Research Institute

Fourth Stage: Non-Intrusive Load Monitoring of Whole Premise

Building 1 was employed as a pilot test site to test non-intrusive load monitoring technology for proof of concept (Figure 88). The technology was typically used for commercial buildings or single-family homes, and it was the first time deployed in a multifamily building to disaggregate the load for load analysis.

Figure 88: Non-Intrusive Load Disaggregation Using Building 1 as a Pilot Building

Source: Electric Power Research Institute

Fifth Stage: Common Area

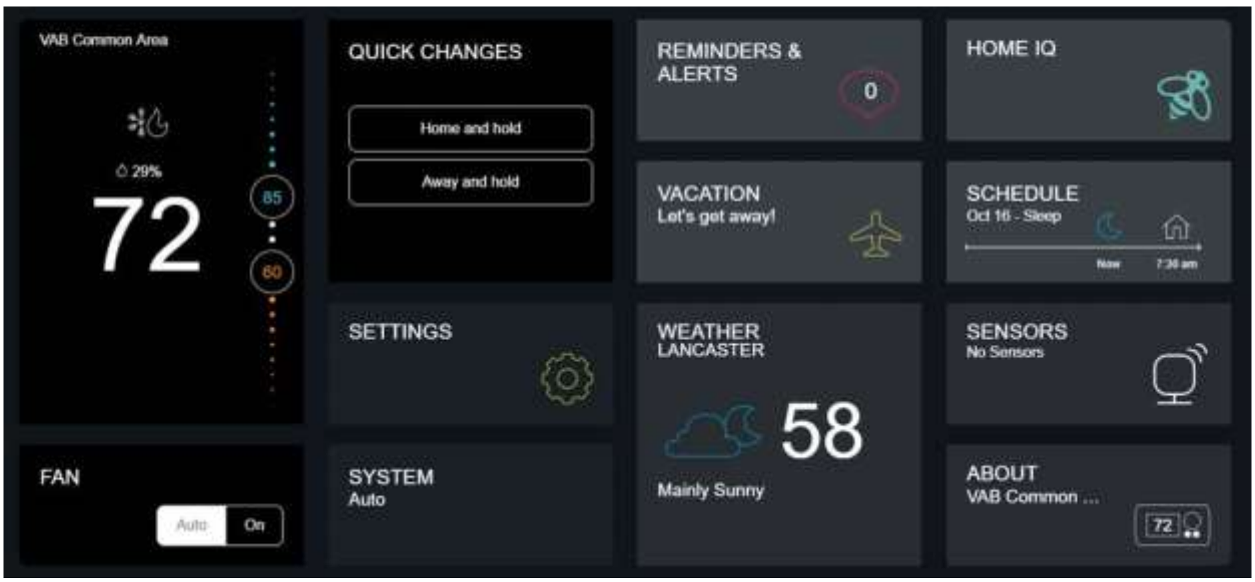
The energy performance of the common area improved with the aerosol leakage reduction technology, foam roof insulation, ducts improvement, and economizer. The blower door test, results of which are shown in Table 47, shows the gradual improvement of the building envelope as aerosol sealing, foam roof insulation and duct insulation are installed. The CFM leakage was reduced by 490 in the depressurization test and 1280 in the pressurization test at 50 Pascal. The results show that the envelope was greatly tightened with the VER installation. Figure 89 shows the indoor air temperature of the common area was kept at 72 ˚F as the research team logged in on a Sunday night. The weekend schedule had a 60 ˚F to 85 ˚F deadband, and indoor air temperature stayed in the comfortable range, which shows the insulation level was considerably improved.

Table 47: Blower Door Test Results of the Common Area

Blower Door Test All tests conducted @ CFM 50 Pascals (+ -)	BASELINE CFM 12/4/14	CFM After Aerosol Seal applied 5/9/16	Incremental CFM Change	% of Original CFM Leakage	Incremental Air Leakage Change	CFM After Foam Roof/Ducts plus Economizers added 10/11/16	Incremental CFM Change	% of original CFM leakage	Incremental Air Leakage Change	Final CFM/ Change from Baseline
Whole Building Test Depressurized CFM -50 Pascals	3,950	3,645	-305	92%	-8%	3,460	-185	88%	-4%	-490
Whole Building Test Pressurized CFM +50 Pascals	4,495	4,010	-485	89%	-11%	3,215	-795	72%	-17%	-1,280

Source: Electric Power Research Institute

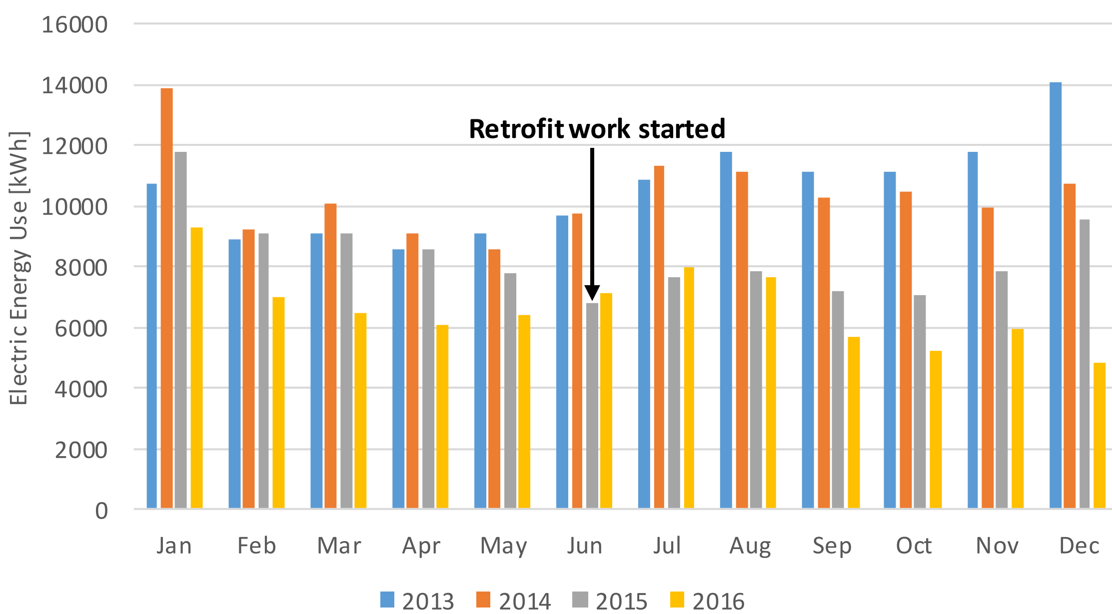
Figure 89: Smart Thermostat Interface of the Common Area on a Summer Sunday Night



Source: Electric Power Research Institute

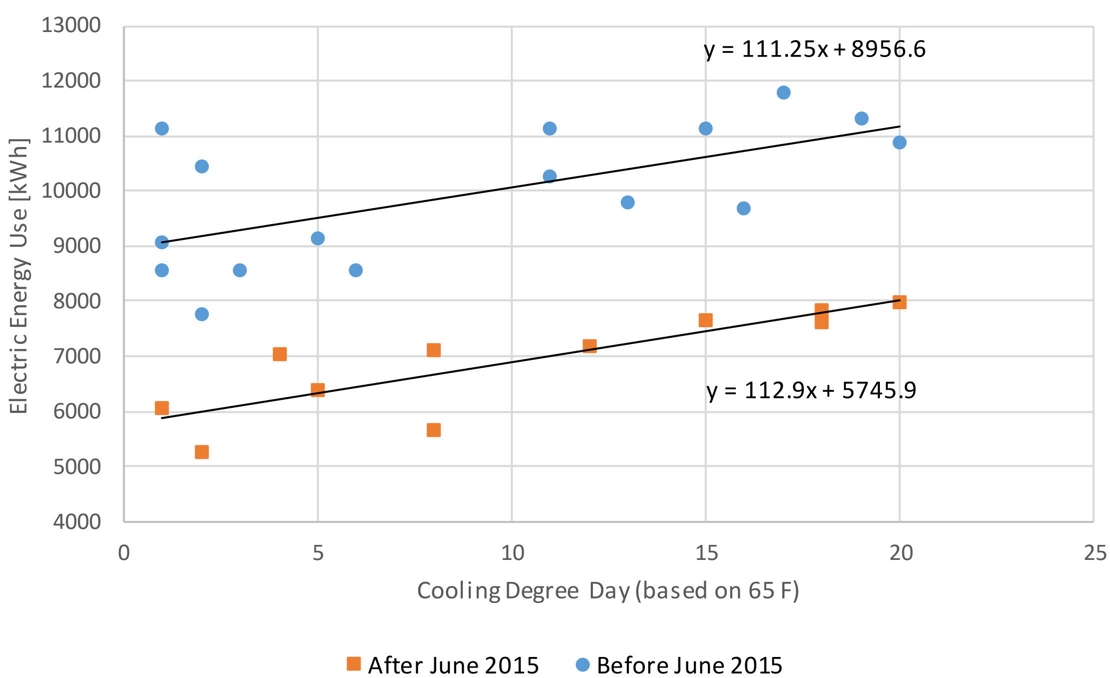
Figure 90 shows the electric energy use of last four years for a month-by-month comparison. Most of the retrofit work at the common area started in May 2015, and the data shows a large reduction starting June 2015 as a result of the VER package of the common area, including LED lights, Aerosol sealing, reroofing, re-ducting, smart thermostat and economizer (the last two items began operation during Fall of 2016). Most of the energy savings resulted from the improved building envelope and more efficient operations of the RTU. Therefore, the regression analysis was based on data before June 2015 (blue dots) and after June 2015 (orange dots) to investigate the electric energy use vs. cooling-degree days. Results are shown in Figure 91. The graph shows that the much improved building envelope and consequent reduced operation of the RTU helped bring down the energy use by roughly 36 percent during the cooling season.

Figure 90: Electric Energy Use of Last Four Years



Source: Electric Power Research Institute

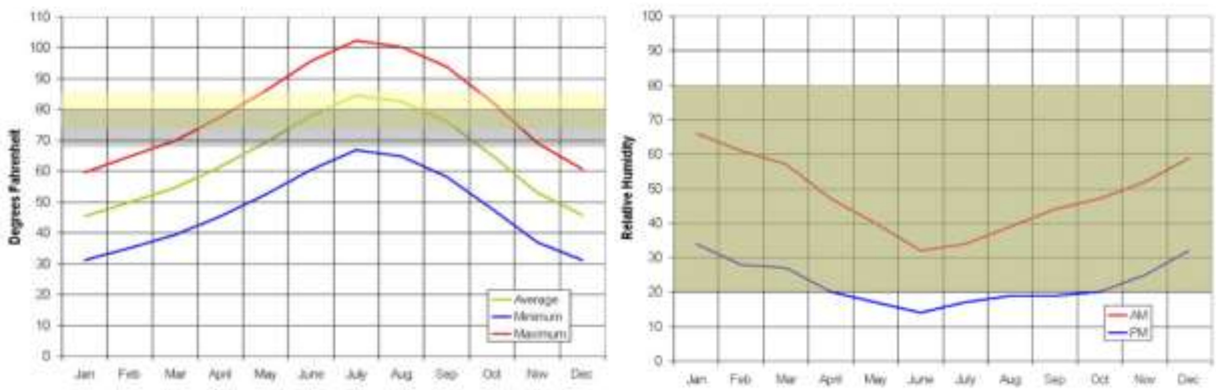
Figure 91: Electric Energy Use of Common Area Before and After Envelope Retrofit



Source: Electric Power Research Institute

In October 2016, the common area was upgraded with economizers that use outside air for cooling when it is cool enough. This reduces the need for refrigeration-based cooling and saves electric energy. Lancaster is in California climate zone 14, which is characterized by wide swings in temperature between day and night, as shown in Figure 92. Hot summer days are typically followed by cool nights, thus providing an excellent opportunity to use economizers to night-flush the building and take advantage of early morning cool outside air to provide free cooling. There are four types of economizers in the market: dry bulb, enthalpy, differential enthalpy and integrated differential enthalpy. The dry bulb option was chosen for reasons discussed in Chapter 3.

Figure 92: Historical Weather Statistics of California Zone 14

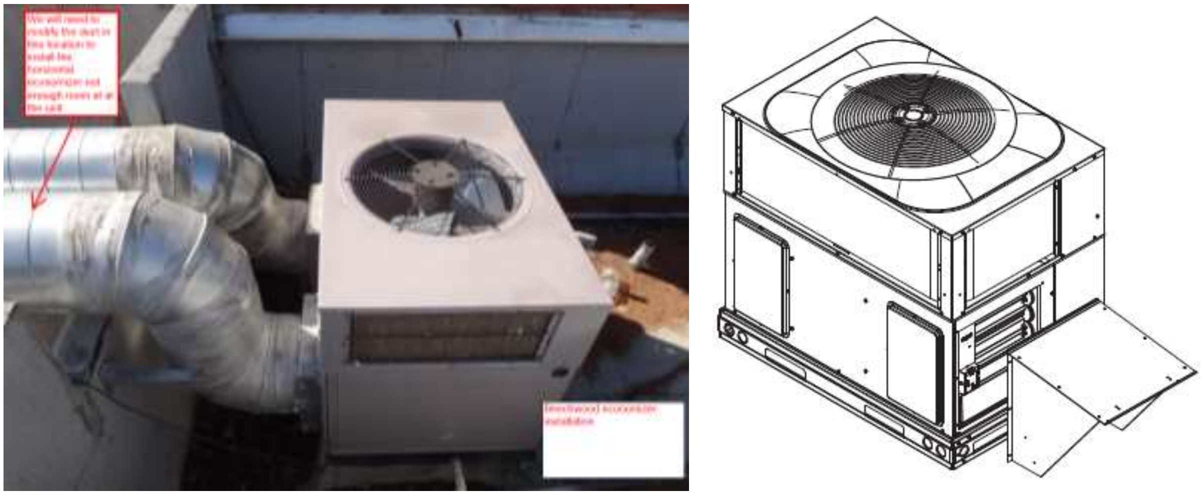


Source: Electric Power Research Institute

The upgrade work was implemented on both the 2-ton and 4-ton RTUs. The power usage of the rooftop units was monitored along with supply, return and exhaust air temperature and relative humidity. The economizer ducts outside air into the building when it is cool outside, using fans to flush warm air from the building. This usually happens on cool summer nights when the building is not occupied (Figure 93). The operational changes were monitored to document the change of energy use.

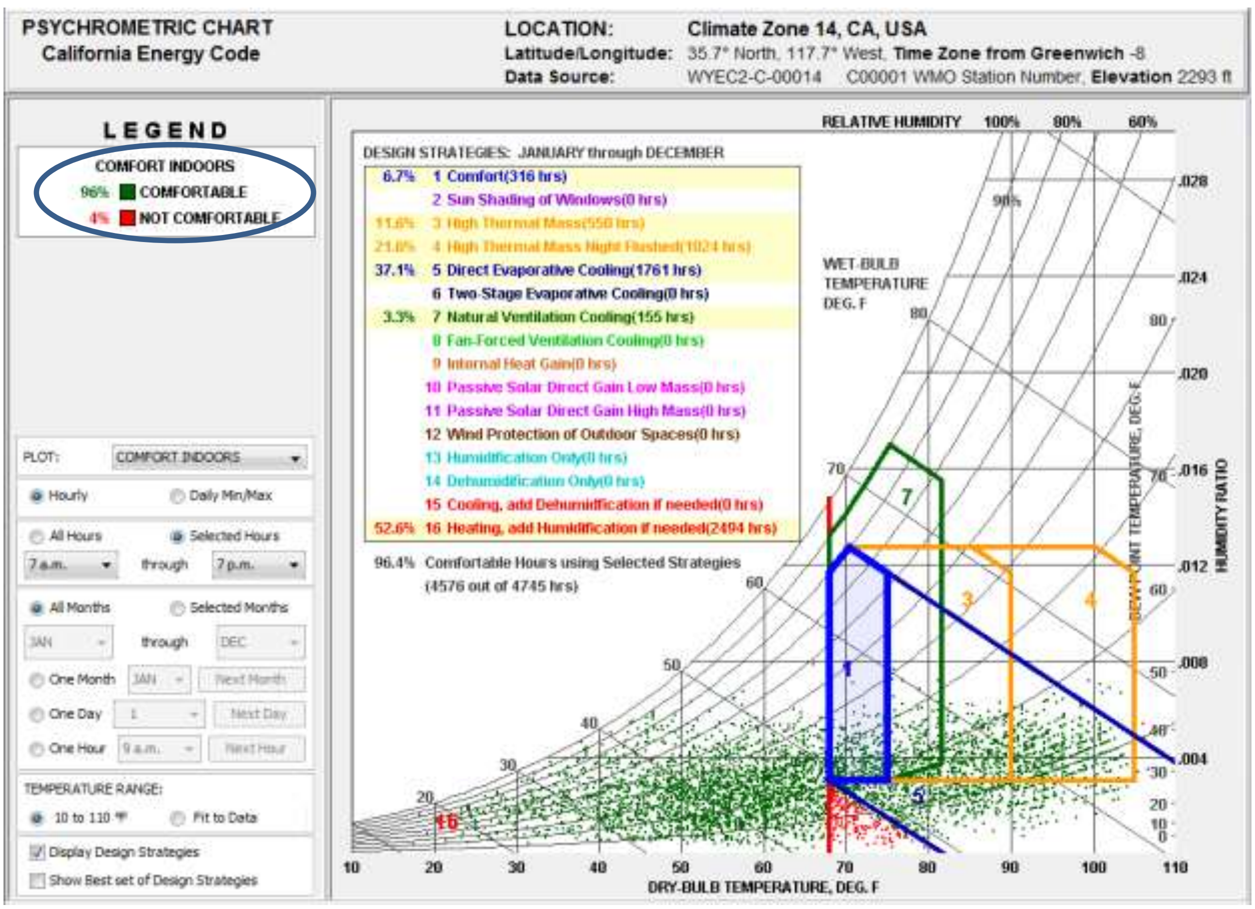
By circulating fresh outside air into the building, the economizer creates a healthier environment for occupants by minimizing recirculation of stale air, as well as improving occupant comfort. Figure 94 shows that the expected comfortable hours can reach 96 percent of the year with the installation of an economizer. The team collected the indoor dry bulb temperature and relative humidity and plotted the data on a psychrometric chart to compare the actual results and the expected values. While the data meets the 96 percent comfortable level, it is inside the comfortable band.

Figure 93: Economizer Upgrade of the Rooftop Units on the Common Area



Source: Electric Power Research Institute

Figure 94: Expected Indoor Comfort Level with the Economizer Retrofit



Source: Electric Power Research Institute

Cost-Effectiveness of the Very Efficient Retrofit Package and Possible Solutions to Split Incentives

As discussed earlier, the VER package greatly reduced energy use in the retrofitted buildings (and individual dwelling units) when compared to control buildings (and individual dwelling units) that were not retrofitted with the VER package. Given that fact, it was desirable to determine the cost-effectiveness of the VER packages. This section details how the cost-effectiveness was determined and the results of those analyses.

Calibrated Computer Models and Simulations

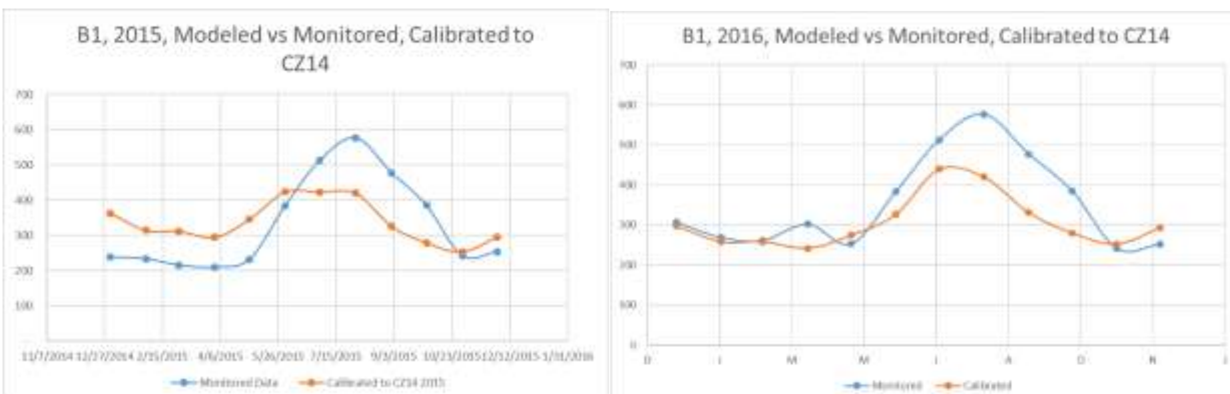
To evaluate the cost effectiveness of the VER package installed in the Beechwood buildings, the research team first had to understand the accuracy of the models used to determine the savings. Computer models included assumptions like the weather (which can be in a standard weather file containing many years of hourly average temperatures and other weather factors), the heat released into the building by its occupants, and electricity used by small devices plugged into the wall sockets. The algorithms, through a series of calculations, predict the effect of changing the efficiency of a certain element of the simulated building, for example, changes in elements such as walls, roof insulation, and window characteristics. The accuracy of these calculations was a result of simulations that had improved over many years to be very accurate when controlled assumptions were used. Other elements in a home, such as a change in air conditioner efficiency can also be simulated very accurately, provided assumptions such as thermostat set-point accurately represent the thermostat settings used by the occupants. The most difficult end-use to accurately model and thereby produce an accurate simulation were miscellaneous electric loads (MELs).

As part of the initial audits at Beechwood, the research staff surveyed occupants regarding the small electric devices they had plugged into their wall sockets: for example, what devices did they have, and how were they typically used? To answer these data needs, survey staff provided a list of questions and common small electric devices. The team developed this survey form several years ago and refined it over the years on different research projects where accurate simulations were needed. The occupant was asked to indicate on the form the devices they had and how they were used: how often, how long, when not using, unplugged or plugged, and left on/off/standby, and so on. The survey also inquired about thermostat set-points and how the occupants used their thermostat (steady, set-back, accelerator, and so on.). Staff also looked at the thermostat (given the opportunity and permission from the tenant) to directly observe the setting and record it next to the claimed setting. As is typical, the survey findings were quite varied, but provided insights and commonalities that the team used to calibrate its models. Two important assumptions used to calibrate the model were the thermostat set-point temperatures for heating and cooling and the MELs settings. However, in this analysis of the Beechwood buildings, the weather changed substantially from pre-retrofit to post-retrofit, requiring special tuning for these weather effects.

The hourly output from the BEopt computer models were calibrated using both the standard weather files (TMY3 datasets) and local hourly weather data from the previous year (2015) and the then-current weather. These comparisons allowed the team to understand the differences between the hourly temperature data in the TMY3 weather files the simulation and the actual temperatures in the monitored data: for example, Jan 2014 to Sept 2016. The calibrated 2015 models had a -4 percent difference compared to billing data, on average. The calibrated 2016 model had a -8 percent difference compared to billing data, on average.

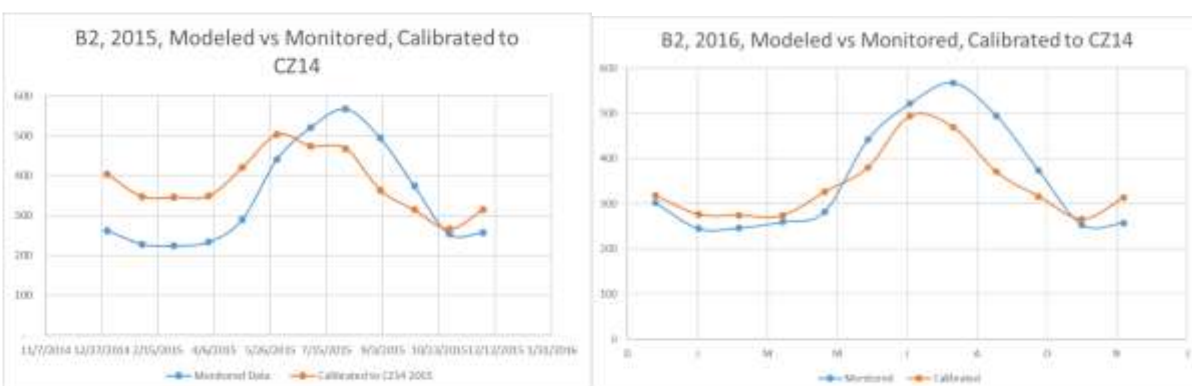
Figure 95 and Figure 96 show overlay plots of calibrated simulated results and actual monitored data. Those calibrations included increasing or decreasing the energy used for heating or cooling in proportion to the differences between the TMY3 average weather and the actual weather from a nearby weather station. During the cooling months the kWh used by the AC (compressor and fan) were scaled, and during the heating months the therms used by the furnace were scaled. Only one was scaled at a time. The energy use was scaled using the percent difference in temperature between the weather file and the actual recorded weather. For instance, if the temperature in the TMY3 file was 20° during an hour in January 2014, and 30° on the same day, same hour in 2015, the energy for heating for that hour was scaled 20/30.

Figure 95: Building 1, Actual vs. Modeled Kilowatt-hours (per Month), 2015 and 2016.



Source: Electric Power Research Institute

Figure 96: Building 2, Actual versus Modeled Kilowatt-hours (per month), 2015 and 2016



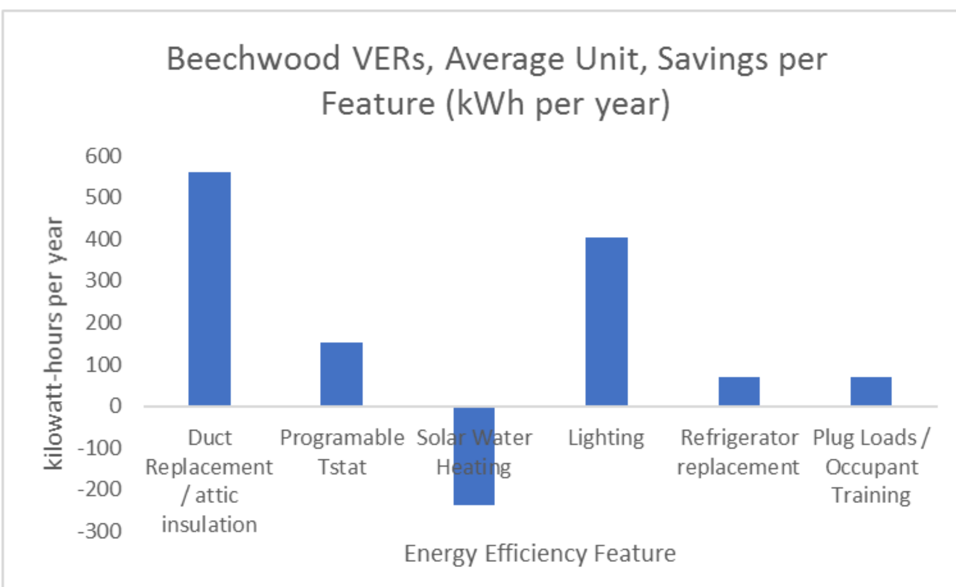
Source: Electric Power Research Institute

End-Use Energy from Calibrated Models

The team was interested in the amounts of energy used for each end-use because that information could be useful in determining future actions and behavior for further reduce energy use. Such detailed energy use information would best come from detailed monitoring at the single electric breaker level. However, that level of detailed monitoring was not planned, budgeted, nor performed in this project at Beechwood. The next best option was to use the simulations, which were not only accurate as yearly averages, but had very similar load-curves. Using this logic, simulation results from the calibrated models were recorded by end-use. That data was used to develop percentages of the total electricity and of total natural gas for each end use. The end-use percentages per end-use were multiplied by the total electricity or natural gas to estimate the amounts of energy used for each end-use.

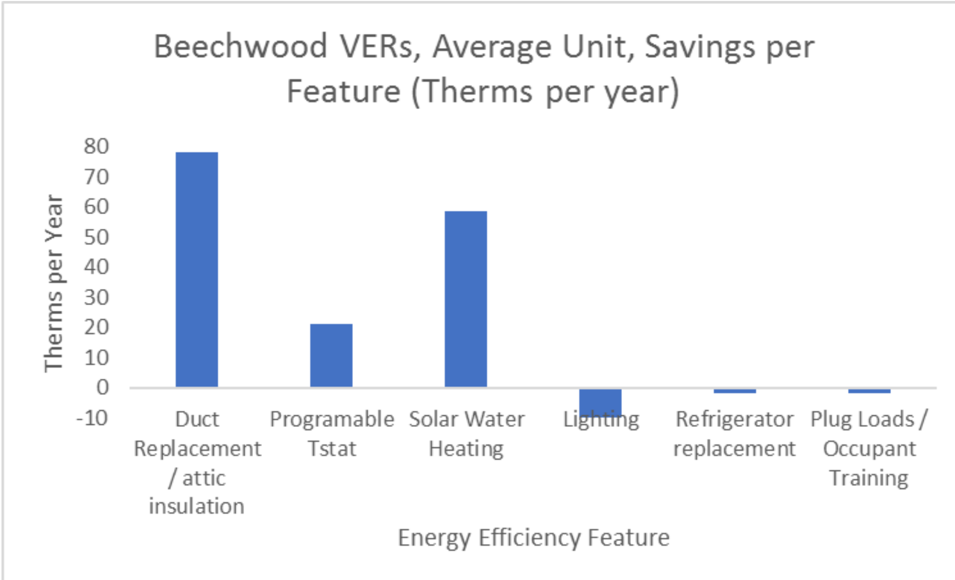
The calculated average energy end-use savings values for the residences at Beechwood are shown in Figure 97 and Figure 98. These graphs show energy savings by end-use. All of the end-use savings are positive in the graph in Figure 97, except for electricity use for solar hot water. Solar hot water was a retrofit as part of the VER, and the solar hot water, which uses electricity to pump the water through this active-solar system, shows up as a decrease in energy savings because there were no solar hot water pumps prior to the installation of this system. Figure 98 shows a large net natural gas savings from pre-retrofit to post-retrofit scenario, more than making up for the new electricity end-use for solar water heating.

Figure 97: Post-Retrofit Electricity Savings by End Use at Beechwood



Source: Electric Power Research Institute

Figure 98: Post-Retrofit Natural Gas Savings by End Use at Beechwood



Source: Electric Power Research Institute

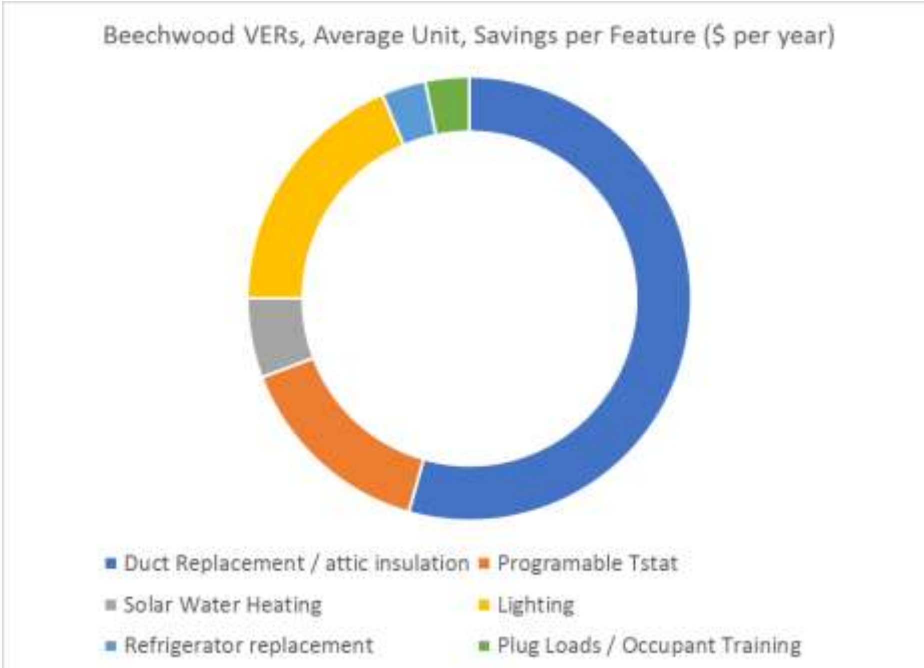
Notice that there is a small “negative savings” in natural gas used for space heating, due to more efficient lighting that contributes less waste heat. This waste heat reduction also reduces cooling loads in summer.

Residence Very Efficient Retrofit Package Energy and Energy Cost Savings

The cost-effectiveness of the VER package is illustrated in Figure 99, where a ring-chart shows the distribution of energy-cost savings produced by each efficiency measure in the VER retrofit at Beechwood. This graph shows the relative importance of each feature in the VER, as predicted by the calibrated models. Some interesting highlights clearly visible from this graph include the relative importance of the retrofits to the duct system, lighting, and programmable thermostat, and the relative lack of importance of the refrigerator, solar water heating, and plug loads. The refrigerator savings were small, because in recent history, refrigerators have gone from using substantial amounts of energy to relatively small amounts, reaching a point of diminishing returns. The savings from the VER package for MELs were also small, because very little was done to reduce MELs in this VER package. MELs reductions at the time of project completion came mostly from increasing the efficiency of the small electric devices, and some minor behavioral change.

Interestingly, the savings from improving the ducts were dramatically less than predicted by the simulation due to poor thermostat behavior, such as leaving the furnace or air conditioner on “high” when not at home, and keeping the space warmer than expected in the winter.

Figure 99: Chart of the Energy-Cost Savings by Feature using Calibrated Model



Source: Electric Power Research Institute

Data used to generate the ring-chart in Figure 99 is provided in Table 48.

Table 48: Tabular Energy and Cost Savings from the Very Efficient Retrofit Package

Savings Per Feature (Average Unit)			
	kWh / year	Therms / year	$ / year
Duct Replacement / attic insulation	560	78	$ 152.70
Programable Tstat	152	21	$ 41.54
Solar Water Heating	(236)	59	$ 16.26
Lighting	404	(10)	$ 52.11
Refrigerator replacement	70	(2)	$ 9.05
Plug Loads / Occupant Training	70	(2)	$ 8.96
VER Package	988	152	$ 281.52

Source: Electric Power Research Institute

To calculate VER package cost-effectiveness it was necessary to calculate the value of the energy savings and then the costs of the feature(s) that generate the savings. An example tabulation of energy and energy-cost savings is in Table 48. One can immediately see the relative values of the energy savings in the third column, with the duct replacement and addition of insulation filling the drop-ceiling area that contains the ducts and distribution box.

The actual kWh savings were extracted from the monitored data. That data was used to compare the test groups (that had the VERS installed) and the control groups, and to determine the difference between the two, producing the savings. This was done carefully, and with high resolution, because use patterns and weather changed year to year.

The rooftop unit (RTU) data was preferable to the SCE advanced metering infrastructure data for making this comparison because it was the most complete, having data from all 10 apartments for both test and control dwelling units. The SCE billing data did not have that level of depth.

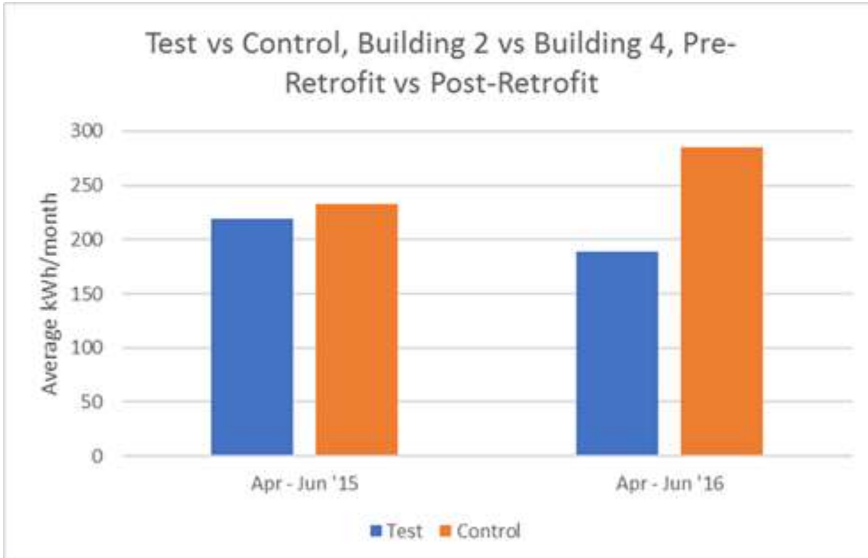
Monitored data from the RTUs from April-June 2015 was collected from apartments pre-retrofit. Post-retrofit data was collected from July 2015 – Sept 2016. SCE billing data spanned from January 2014 – Sept 2016. Both pre- and post-retrofit SCE data sets were incomplete. Using the RTU data, the research team compared pre- and post-retrofit. The results were unexpected in that the energy use in the retrofitted buildings went up. Several analytical techniques were employed to determine why as well as how to use this data to evaluate the effectiveness of the retrofit and trust the results.

Separating the Effects of Weather from Energy Efficiency Measures on Energy Savings

The weather in 2016 was substantially warmer in the summer and cooler in the winter, making pre-post energy savings calculations difficult. The four bars in Figure 100 show the results of paired data from both test and control groups for the same three months, one year apart. This shows a major increase in kWh use for the same three months for the control group, and a small increase for the test group, when one would expect a lower energy use due to the retrofit.

The months of April-June were used for the comparison in Figure 100 because they are the only data available where both test and control, both pre and post, for the same season – cooling, albeit early for April can be compared. The reason this comparison was important was that it combines pre- and post- analyses, which were most likely the same or mostly the same tenants, who were likely to have essentially the same behaviors before and after the retrofits, and where the same months are used so the team can control for the significant weather changes between 2015 and 2016. The result is that, despite the fact that both the test and the control buildings' energy use went up from 2015 to 2016, the control group RTU kWh data went up 51 percent while the test group RTU kWh data went up 6 percent, producing a net savings of 45 percent for the test group compared to the control. The SCE data, even though some of it was missing, produced the same results.

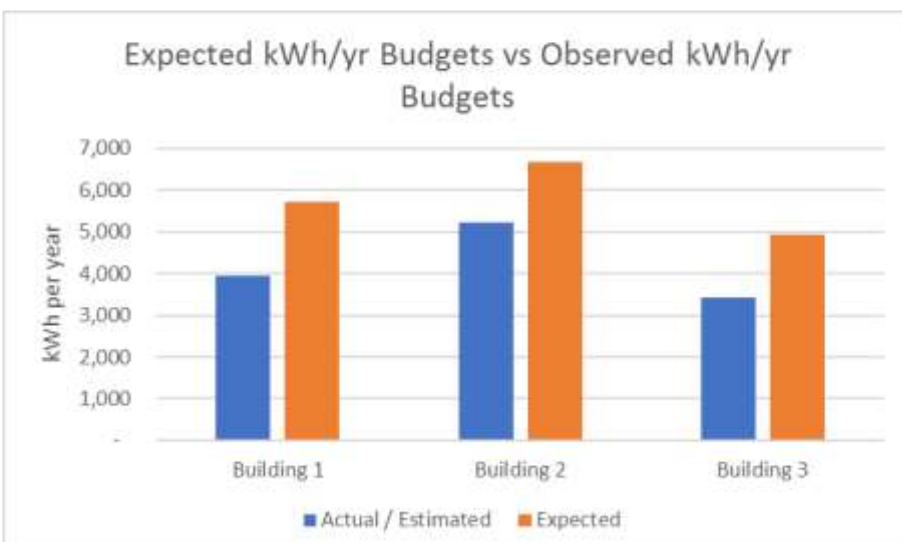
Figure 100: Three Months of Comparative Kilowatt-hour Data from Test and Control Buildings, Pre- and Post- Retrofits



Source: Electric Power Research Institute

The large impact of the much warmer weather in the second year of a two-year test period merits further examination. The result of another analytical technique is shown in Figure 101. In that analysis, the differences in weather were used to extrapolate the measured kWh data recorded in 2014 and 2015 to what would be expected, per apartment, based on the increase in summer temperatures, to the actual kWh use by the test apartments. This approach to separating the weather effects from the actual savings showed an average of 39 percent, with two of the buildings' savings at 44 percent and 45 percent.

Figure 101: Differentiating the Effects of Weather Change from Very Efficient Retrofit Energy Savings.

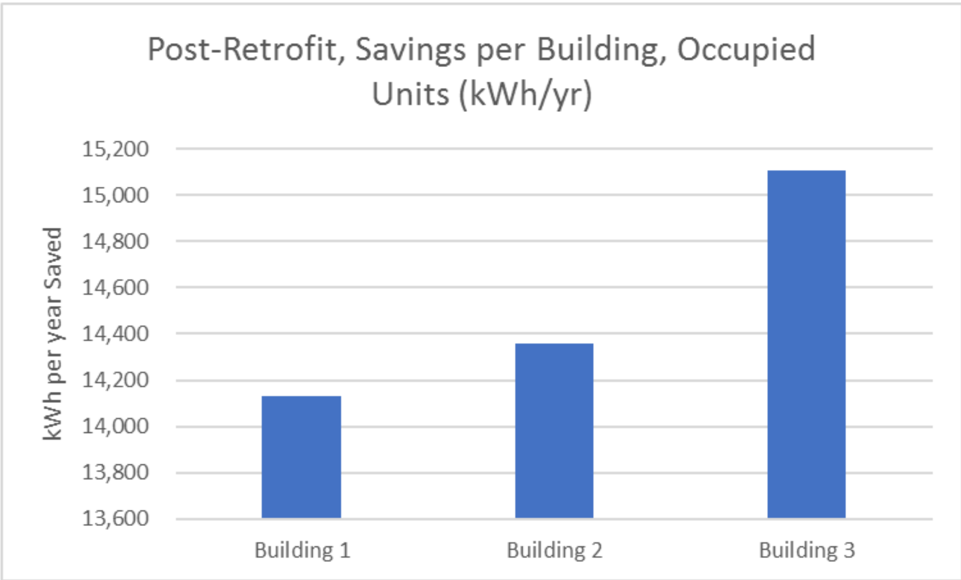


Source: Electric Power Research Institute

Best Estimates of Very Efficient Retrofit Package Energy Savings

In the last section, the distorting effects of weather changes were separated from the VER package kWh savings, which in those evaluations were likely between 40 percent and 50 percent. To determine the cost/benefit ratio actual energy savings are necessary. Having isolated the savings percentages, they can be used to convert back to energy units. The results are shown in Figure 102.

Figure 102: Kilowatt-hour Savings in the Three Test Buildings



Source: Electric Power Research Institute

The data were plotted this way to show both how similar the savings were between Buildings 1 and 2, and the larger savings for Building 3 are due to the foam insulated roof shaded by the solar collectors. The tabulated kWh savings are in Table 49.

Table 49: Tabulated Energy Savings from Very Efficient Retrofit Package in the Three Multifamily Buildings

Building #	2016 Savings, per unit (kWh/yr)	# of Units	Savings per Building (kWh/yr)
1	1,766	8	14,131
2	1,436	10	14,359
3	1,511	10	15,109
	Total	28	43,599

Source: Electric Power Research Institute

Once the electricity (kWh) savings have been established, similar mathematical manipulations were needed to tease the natural gas savings, which is more difficult because the natural gas is master-metered. Therms savings were determined in similar fashion a kWh savings, with the caveat that master-metered gas necessitated some estimation. The results are compiled in tabulated form in Table 50.

Table 50: Tabulated Monthly Therm Savings

2016	
Month	Therms Savmgs
Jan	656
Feb	-1,130
Mar	73
Apr	237
May	1,083
Jun	95
Jul	434
Aug	446
Sep	373
Oct	2,327
Nov	-15
Dec	74
Total	4,653

Source: Electric Power Research Institute

Financial Analyses of Very Efficient Retrofit Package Energy Savings and Photovoltaics

The kWh and therms savings, having been derived as presented above and the results analyzed to be confident in the results, can be converted to energy costs, and using those, various cost-effectiveness calculations can be performed. Cost-effectiveness calculations clearly require accurate costs to perform the retrofits are required. The costs and any incentives for the installation of the VER package were obtained from the construction manager, Primus Energy and SCE. PV costs were obtained from meeting notes with the team. The full costs of installing the VER package were verified with LINC to derive the full costs of VER + PV. These construction costs are tabulated in Table 51.

Table 51: Estimated Costs for Very Efficient Retrofit Package Retrofit and Photovoltaic Installation.

PV Installation	$332,177
EE (no Asbestos)	$368,281
Total Project Cost	$926,805

Source: Electric Power Research Institute

The kWh and therms savings from the VER package ("EE") were compiled into tabular form and are shown in Table 52along with some simple payback estimates. Using known energy costs for the site, the value of the savings due to the VERs were calculated. Using the optimistic assumption that all apartments are occupied and paying rent, with electricity savings compiled at $0.165/kWh, and $0.92/therm, rates which are applicable to LINC but not to most of the tenants, two simple payback estimates were calculated. One was under current policy and regulations, which stipulate that the benefits from the retrofits follow the meter. Under that assumption the payback to LINC would be 86 years, not a timeframe that would encourage retrofits. Under an alternative assumption that the savings accrued to the party which paid for the upgrades, in this case LINC, and using average utility rates, the payback period shortens to 32 years. With a certain amount of value engineering, technology improvements or changes in approach, combined with better incentives, it may be possible to reach an economically attractive package.

Table 52: Energy Cost Savings and Very Efficient Retrofit Package Costs to Calculate Simple Payback

	$ Saved Per Year	Rate	Cost	Simple Payoff
Gas	$ 4,280	$0.92	$ 368,281	86
Electric	$ 7,194	$0.165	$ 368,281	N/A
Total EE	$ 11,474	N/A	$ 368,281	32

Source: Electric Power Research Institute

PV was added to the natural gas and electricity costs and benefits, and the cost-effectiveness of the PV+VERs occupied package analyzed. The results are tabulated in Table 53 and the energy cost savings are illustrated in Figure 103.

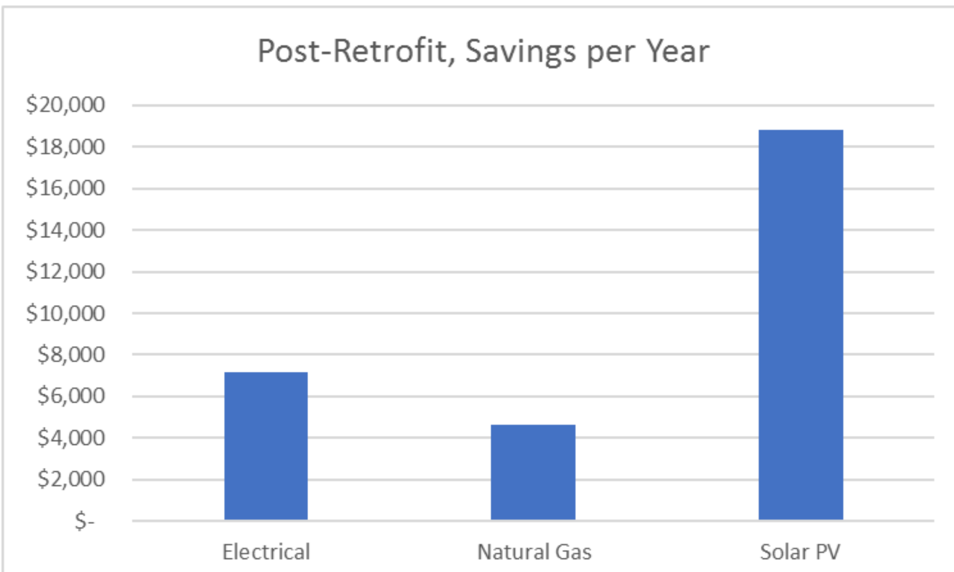
Table 53: Differences in Simple Payback with Different Recipients of Utility Savings Benefits.

	$ Saved Per Year	Rate	Cost	Simple Payoff
Gas	$ 4,280	$0.92	$ 368,281	86
Electric	$ 7,194	$0.165	$ 368,281	N/A
Total EE	$ 11,474	N/A	$ 368,281	32
PV	$ 19,390	$0.165	$ 331,800	N/A
Gas + PV	$ 23,671	N/A	$ 700,081	30
EE + PV	$ 30,864	N/A	$ 700,081	23

Source: Electric Power Research Institute

Several different potential approaches are illustrated that could be considered to improve the financial ramifications of performing deep energy retrofits. LINC's current situation, with gas master-metered and electricity metered at the individual residences, and the savings benefits following the meters, the simple payback without PV is 86 years. If the currently heavily subsidized PV costs and benefits are added, the payback is reduced to 30 years. A superior solution for the property owner or other party paying for the retrofits would be for the entity paying for the upgrades to receive the benefits. With that scenario, the simple payback for funding the entire VER package and accruing both gas and electric savings is 32 years, still longer than the mortgage and likely not tenable. If PV with current incentives is added to this better scenario where the entity funding the upgrades receives the benefits, now electric, gas and PV, the payback is 23 years. This is likely an economic possibility for property-owners and is worth researching how it could be evaluated and the possibility and likelihood of putting it into practice.

Figure 103: Energy-Cost Savings from the Entire Very Efficient Retrofit Package for Electricity, Natural Gas and Photovoltaics



Source: Electric Power Research Institute

Thus, the best-case scenario for a realistic return on investment includes incentives, PV, and the energy-efficiency returns resulting from implementation of the VER package. Using these values, the project's success for the occupied apartments was evaluated.

Annual financial considerations were included to develop two additional cost-effective metrics (years to positive cash flow, and years to amortized payback) to analyze the value of the package within the project itself, not just best-case scenario. These are included in Table 54.

In this case, returns were corrected for inflation (assumed 2.5 percent over the next 30 years and used the 2017 United States Energy Information Agency projected price escalation) and for the increase in the price of fuel (also 2.5 percent over the next 30 years) 0. Using these projections, financial calculations were performed based on a 30-year loan period. Simple payoff was calculated using both 0 percent and 2.5 percent fuel-price escalation. Amortized savings included a combined 5 percent escalation for fuel and inflation. The results from this analysis are provided.

Table 54: Comparison of Different Cost-Effective Metrics

	0% Annual Increase	2.5% Annual Increase	5% Annual Increase	EIA Projected Escalation
Simple Payback	27	21		
Years to Positive Cash Flow			17	20
Years to Payback, Amortized			31	33

Source: Electric Power Research Institute

The analyses clearly show that, if the investing party can collect the benefits, then it can be a good investment to perform the VER package retrofits and the along with installing PVs. PV and EE costs were as indicated in Table 51. Billing savings in Table 52 were calculated on average costs for Beechwood: $0.135/kWh and $0.88/therm (USEIA, 2017).

Current regulations require that energy-cost savings basically follow the meter and accrue to the party paying bills related to the energy meter, certainly the simplest approach for accounting. The result of this policy, using this VER retrofit as an example, would be that LINC spent $368,281 to perform deep VER package retrofits (not including asbestos abatement costs), and in return their annual gas bill would be reduced by $4,280, and their tenants' bills as a group reduced by $5,886 annually, or $210 per apartment per year.[4] There is no economic driver for multifamily dwellings to be retrofitted by the building owners unless they pay all the utility bills, in which case their tenants have no financial incentive to not waste energy.

Deep Energy Efficiency – Need for Policy Updates and Change

PV and efficiency are viewed and treated differently in the building, real estate, and financial industries. With PV one can accurately predict the weekly, monthly, and annual generation using PV modeling and simulation software, and one can literally bank calculated generation numbers. This is the case because one can also directly measure the actual production of a PV array by looking at the output of the inverter or using some other method to monitor the energy from the array and ultimately into the electrical panel.

Energy efficiency is not as simple because it is spread across all of the uses that add up to the monthly electric bill. However, it can be calculated and, as shown in this section of this report, even under difficult situations such as large changes in weather that confound the difficulties in measuring energy savings, there are very good correlations between predicted energy use and savings from calibrated models and the actual savings that can be measured, although more difficult than for PVs.

[4] See next section for thorough examination of the financial benefits of deep retrofits in multifamily housing.

The models used to calculate building energy use and energy savings are every bit as good as the PV simulation models. However, building occupants can make these correlations more challenging and even change the quality and quantity of the energy use compared to the simulation by using thermostats differently than modeled, or by using energy-consuming equipment not in the model. These can make the model appear to be wrong, but instead, it was the assumptions made in the inputs to the model that were wrong. In that case, the predicted savings have been masked by the unanticipated events. If one were to track their PV generation not before it enters the electrical panel, but after, where it becomes part of the larger, "noisier" data, they would find that monitoring PV production under those conditions is akin to directly measuring energy savings from deep retrofits.

That is an overly simplistic comparison, but the reality is that very sophisticated, very accurate, and relatively simple-to-use building energy modeling and simulation software is available today, and it can be used by qualified practitioners to accurately predict energy savings due to efficiency retrofits, as well as they can predict PV generation, especially when cloud events and other such normal phenomena are considered.

To foster change in the financial support of efficiency upgrades, the efficiency community needs to stop differentiating themselves from the renewable community and embrace them and their practices, if for no other reason than to be able to secure financing for deep retrofits just as easily as one can secure financing for PV systems. Further, state and federal policies need to be updated to recognize efficiency as thoroughly reliable. Policies that impact efficiency differently from local generation should be updated to view and treat efficiency and treated equally with generation, especially in the financial community, so that they adopt efficiency and change to provide as wide a variety of financing vehicles for efficiency (including purchase, lease, power purchase agreement, and so on) as are available for obtaining PVs.

CHAPTER 9: Financial Models for Scalable Implementation

To meet its energy and carbon reduction objectives, California must achieve large energy savings from all building sectors, including low-income multifamily (LIMF) properties, which by their very nature operate on thin margins that are insufficient to support needed upgrades. Thus, a full menu of financial tools is critical to realizing these improvements. This chapter identifies the major barriers to financing efficiency retrofits in the LIMF market and provides recommendations to address them.

The most difficult of these barriers is the "split incentive" which occurs between a landlord and a tenant. In the program evaluation literature, this concept is sometimes alternatively referred to as the "principal-agent problem" (Dyson, Chen, and Samiullah, 2010). The split incentive problem cuts across many other barriers, making it perhaps the most critical barrier to resolve. It has long been a prominent concern of multifamily energy efficiency program designers. In fact, the split incentive barrier is often the only market barrier that is explicitly mentioned when reports discuss the challenges faced by multifamily energy efficiency programs. The American Council for an Energy-Efficient Economy (ACEEE) notes that the split-incentive barrier is in fact a market failure. The split incentive is the primary barrier addressed here but also mentioned are several other notable barriers encountered during this research project.

The split incentive barrier occurs when owners do not pay the energy bills and have no financial incentive to invest in measures that will reduce energy consumption. Tenants have little incentive to invest in a property they do not own and often occupy temporarily. In master-metered properties, the owner does have an incentive to invest in energy efficiency, but the tenant has no incentive to save energy. Considering the large effect of tenant behavior, this is potentially even worse, especially in rent-controlled apartments.

At the Beechwood property, the electricity was metered at individual apartments, but the natural gas was master-metered. There are other factors to consider in low-income properties, where tenants have minimal-to-no control over improvement decisions made at the property, and limited income to invest in energy efficiency improvements. In addition, there is often a high turnover rate in LIMF communities, further diluting any likelihood that tenants would invest in property improvements of any kind. Complicating things even more is the fact that rents in affordable housing are regulated and restricted, and owners cannot simply increase rents as improvements are made.

Unfortunately, there is no financial model, playbook or roadmap for addressing the barriers to arranging the financing behind the deep, near-zero energy retrofit of a low-income multifamily property while addressing the split incentive barrier. The team's experience during this research project was validated in a February 2017 report by the Clean Energy Group that identified the lack of an integrated development finance model as one of the most formidable barriers to high-efficiency low-income multifamily projects (Sanders and Milford, 2017).

Lessons learned in high-end commercial markets driven by economics simply do not apply to LIMF developers, who when looking at retrofitting properties are often also interested in the environmental, social and public health consequences of their investments.

While some question the impact of the split incentive on multifamily housing energy consumption, it is real. For example, WegoWise, a company that remotely analyzed building energy consumption, wanted to know how much more energy apartment-dwellers consume when they do not have to directly pay their bill. The company looked at 3,000 multifamily and affordable housing units throughout Massachusetts and found that tenants used 30-percent more BTUs per square foot when landlords had to pay the bills. The company also found that annual utility costs for landlords were 20-percent higher than when tenants directly paid the bills (Lacey, 2014). While there are many other similar stories, this example points out that the barrier is a legitimate concern and worth addressing in LIMF housing.

To address the split incentive barrier effectively, owners of multifamily property must not only find financing for energy improvements, but must also simultaneously educate tenants about their energy use so that investments in these improvements are not wasted. Property owners must consider strategies to access the rent stream to finance or pay back energy improvement costs not covered by energy incentives or rebate programs (California Housing Partnership Corporation, 2016. Generally, the owner needs to increase the net operating income for the property and find a pathway for recovering some of the costs of energy improvements.

In an attempt to find this pathway, the team designed, tested, and implemented deep energy-efficiency retrofits of 28 LIMF apartments at the 100-unit Beechwood LIMF property in Lancaster, California between 2013 and 2016. The Beechwood property is master-metered for gas and individually-metered for electricity. In keeping with their mission statement, the owner of Beechwood, LINC Housing, LLC, is committed to providing affordable housing and keeping rents low for their tenants as they invest in energy efficiency, solar and storage.

The project team researched potential utility allowance (UA) energy efficiency adjustments and other policies and measures that aim to provide owners a cost recovery mechanism in rents. Unfortunately, rent-caps and the low-income family's limited ability to pay leave a considerable gap between the cost of efficiency retrofits and ability of LIMF property-owners and tenants to pay for them. This project focused on determining the most cost-effective energy efficiency and renewable energy retrofits to perform, finding government and utility incentives, and financing vehicles that in combination will make the retrofit affordable, while keeping rental payments steady.

Before discussing the details of this topic, it is useful to briefly highlight a handful of key findings and important lessons learned, as the team attempted to address the split incentive barrier during this research project.

Key Findings

The team made a number of important discoveries, including:

- Many of the financial tools identified and considered, including UAs and UA calculators, were complex, difficult to understand, and hard to access.
- Finding, evaluating, and negotiating with various finance programs and tools is time consuming and labor-intensive, leading to large soft costs.
- Despite educational tools and personal communication to explain to tenants the value of behaviors that reduce energy use, considerable energy savings were taken back after the improvements were installed, and some tenants actually increased their energy usage.
- Programs run by the State of California, such as Energy Upgrade California, have hidden costs and restrictions that make them challenging to use.
- Environmental remediation efforts such as asbestos removal are expensive and can lead to delays. They are also inconvenient for tenants and often hard-to-schedule, since they require the tenant to vacate the property for extended periods.

Motivation of Cost Effectiveness and Learning of New Methods

There are five main conditions or triggers motivating multifamily owner investments, with varying degrees of impact (Energy Programs Consortium, 2013):

- Time of owner purchase or refinancing of property (five to six percent of low-income multifamily properties refinance each year).
- Replacement of aging, obsolete, or costly HVAC equipment (five percent of the HVAC units in multifamily properties is replaced each year).
- Attractive utility, tax, and government incentives.
- Health and safety improvements needed in many older properties.
- Optimizing desirability of rental properties to retain tenants and improve or maintain property values.

One of the factors in LINC's deciding to partner on this project was to jointly find or develop methods to make energy efficiency improvements more cost-effective. These methods include technological and construction improvements that make retrofits more affordable, finding utility incentives, government grants and other incentives and programs that reduce costs, including new and innovative financing programs. Replacement of aging equipment was another factor in LINC's decision to participate. For example, LINC was interested in replacing older kitchen appliances and replacing them with high efficiency ENERGY STAR® units. But without cost-effectiveness and absent good financing tools, efficiency improvements will not be done. It is critical to the growing numbers of low-income families to have quality, affordable housing, and to meet that need, the industry needs cost-effective retrofit practices financed by innovative financing solutions. To the extent possible, these financing solutions should reduce the paperwork required and be more mindful of tenant and landlord time. The experience of this research team during this project proved that many current financing solutions pose significant administrative burdens, which effectively rule out many programs from consideration.

Barriers Experienced During the Beechwood Project

The financial barriers encountered during the project are addressed in the current literature, especially those related to split incentives. The majority of recent multifamily energy efficiency reports available for review identify barriers but there is little information on methods for resolving these barriers (Energy Programs Consortium, 2013). Separating financial barriers from other barriers before designing specific solutions to each is no easy task. LIMF property owners report that lenders often put onerous, prescriptive conditions on lending for LIMF property improvements, and often specify higher interest rates on their loans. Other major barriers also tend to have financial components, and these components need to be carefully identified, examined, and analyzed.

In the course of this project, in addition to and often coupled with simple cost and financing barriers, regulatory, administrative, legal, technical, programmatic, behavioral, convenience, and attitudinal barriers were encountered. It is important to identify and separate the direct and indirect impacts that these other barriers can have on the financial health of a project. Unfortunately, the line is blurred between some of these barriers and financial barriers, and overlap is common.

For example, technical, jurisdictional, or even weather-related issues produce construction delays of weeks or months and that delay impacts on the bottom line of the project, and that impact is as financially burdensome as the theft of Wi-Fi devices or the “take back” effect. This effect occurs when tenants of recently retrofitted apartments realize that the resultant reductions in their energy bills is free to them and they choose to spend it on using more energy to be warmer and/or cooler via a simple set-up/down on their thermostats. Tenants responsible for take-back of savings often do not realize that they are reducing the savings that the property owner may have counted on in their calculations of building energy-use and/or energy-costs savings the owner may have used in predicting the energy savings results from “greening” of the apartment complex, and/or their calculations of cash-flow or building value calculations used to justify and even fund the energy retrofits.

Key financial and related barriers faced by the research team, including the property owner, during the retrofit of the Beechwood property include:

- Programmatic financial barriers were subject to the effects of split incentives, and related to restrictions, conditions and eligibility requirements for specific funding sources, especially UA adjustments and California Utility Allowance Calculator (CUAC) requirements, the Energy Upgrade California (EUC) Program, the California Solar

Initiative Multifamily Affordable Solar Housing (MASH) Program, the Energy Savings and Assistance Program (ESA) and the Middle Income Direct Install (MIDI) Program.

- Unusually high cost barriers related to environmental mitigation and asbestos removal efforts in each Beechwood multifamily unit: For example, the cost of asbestos abatement was nearly 70 percent of the cost of the efficiency retrofits, and the asbestos abatement was more than 40 percent of the total cost of the retrofit.
- Technical barriers: These were principally Wi-Fi along with typical construction challenges associated with photovoltaic (PV) retrofit installations.
- Behavioral and informational barriers: These were due to lack of information or concern about energy use and its costs, what effects energy costs, and who is responsible for good energy behaviors and why. For example, at Beechwood, there was considerable "take back" or reduction in energy savings.
- Access to tenant work space barriers: These were caused by a majority of stay-at-home tenants and varying tenant schedules at the Beechwood complex that made it difficult to coordinate the timely installations of energy improvements.

Barriers and potential solutions are discussed in more detail below.

Programmatic financial barriers

Utility Allowances

Gross rents paid to affordable housing property owners are offset for qualifying tenants based on income qualification and realistic utility costs. These standard UAs are set and adjusted annually by the local public housing authority (PHA). Under federal regulation, "…the utility allowance (UA) schedule must be determined based on the typical cost of utilities and services paid by energy-conservative households that occupy housing of similar size and type in the same locality. In developing the schedule, the PHA must use normal patterns of consumption for the community as a whole, and current utility rates."

Theoretically, adjusting this standard utility allowance to reflect savings from energy efficiency and renewable energy upgrades allows the property owner to capture these savings over time to pay for the improvements. It effectively resolves the split-incentive issue, particularly at the Beechwood project because the apartments are individually-metered for electricity. In practice, however, lowering the UA has been shown not to be a strong incentive for owners to install upgrades or to recover savings from their investments. The standard UA does not consider the age of buildings, size of units, number of units, levels of electricity and gas usage, long-term changes in utility rates, or changes in climatic conditions within a county. The standard UA for the Beechwood property was based on utility-cost averages for affordable housing properties across all of Los Angeles County. While Lancaster is located in the harsh, high desert environments of Climate Zone 14, the majority of affordable housing properties in Los Angeles County are located in calmer conditions close to the coast in Climate Zone 6. Furthermore, existing gas and electric utility billing data demonstrates the standard UA for Lancaster is lower than actual consumption. This results in an unrealistic standard UA for Beechwood made it more difficult to calculate the true costs and benefits of an UA adjustment. The Beechwood project was not alone; a 2014 survey of California affordable housing property owners found that few have used adjusted UAs because of regulatory, administrative, and cost barriers 0.

The effectiveness of the UA in resolving the split-incentive barrier is based in part on the housing assistance program in place at Beechwood. Because the lower UA lessens the amount of assistance that they would otherwise have to pay, tenants receive less financial assistance. For affordable housing building owners such as the LINC Housing Corporation, they must raise rents to cover the shortfall caused by the lower UA adjustment. In these cases, the UA adjustment is actually a disincentive for property owners to consider energy efficiency and renewable energy upgrades. As part of its mission statement an affordable housing provider, the LINC Housing Corporation is committed to keeping their rents affordable so after careful analysis the UA adjustment was not used.

The California Utility Allocation Calculator

The most appealing opportunity to the research team to take advantage of energy improvements by using a calculated UA was the California Utility Allowance Calculator (CUAC). Officially recognized since 2009, CUAC is a tool designed to calculate project-specific utility allowances for low-income housing projects. The CUAC must be used by qualified professionals approved by the California Tax Credit Allocation Committee (CTCAC). On a Low Income Housing Tax Credit property like Beechwood (New York Times, 2012) – CUAC is limited to those properties constructed after 2009, or those properties with solar PV using MASH incentives, and not receiving other funding from sources that prohibit it. Beechwood apartments were built well prior to 2009, so these restrictions eliminated subsidies for apartments not impacted by the PVs. This seemed a narrow opportunity, except that LINC decided to install PVs and institute virtual net metering, making the apartments eligible, at least up to that point. However, if the current UA were not representative of the actual conditions prior to using the calculation as with the Beechwood property, even after meeting all of these conditions the new allowance may still not achieve the desired result of adding to the net operating income (higher rent).

An initial application fee of $500 is required for CTCAC to begin reviewing the planned upgrades. Total payments to CTCAC typically increase depending on the complexity of the project and CTCAC's review. While total fees cannot exceed $2,500, the total charged by the CTCAC analyst is not known until CTCAC completes their review and this uncertainty can discourage any evaluation of UA adjustments. CUAC requires extensive compliance documentation (for all 45 input variables) and the purchase of new software; and the software needed to run CUAC is almost ten years old. On top of these barriers, the software does not perform all of the calculations required, so separate spreadsheets are also needed as part of the process. CTCAC incentives are often not attempted due to the overhead burden associated with it, and the uncertainty of any reasonable outcome before all calculations are complete and remittance due.

In addition to the regulatory and administrative barriers to using UA adjustments for the recovery of energy savings from upgrades a final barrier was that the time frame for recovering savings typically w not known. Projected timeframes do not account for changes in occupancy, tenant energy consumption behaviors, PHA updates to the standard UA, or changing federal and state program requirements. LINC and team also determined that the use of CUAC is better suited to larger and more comprehensive upgrades than the Beechwood project. Despite being a very accurate tool for modeling building energy use it also faced regulatory and compliance barriers. To rely on an UA adjustment as a means to finance upgrades was simply not viable or realistic for the Beechwood project.

There are several solutions to addressing the barriers of benefitting from UA adjustments. Given the various federal housing programs, varying UAs from location to location, as well as state oversight of the process, a more consistent tool for measuring electricity and gas usage would be beneficial. At the Federal level, there were efforts underway to improve the use of UA adjustments for recovering cost savings. At the state and local levels, acknowledgement of climatic differences within each PHA and the ability to gather and analyze utility data would also be beneficial to building owners. The Energy Foundation is funding the creators of the CUAC to design a National Utility Allowance Calculator In 2017.

One local California PHA has developed a model UA adjustment option specific to solar PV that holds promise. All PHAs report the UAs based on HUD's reporting template which breaks down electric and natural gas utility costs by end uses such as heating, air conditioning, refrigerator, cooking, water heating, water, sewer, and waste collection among others. The Housing Authority of Tulare County in California has developed a Solar UA which offsets electricity consumption by the amount of PV production credits (Waite, 2013). Tenant utility consumption baselines are estimated for each building type and unit size, applicable utility rates are applied to determine the amount of the utility allowance, and the solar offset is then calculated through a separate process and factored into the utility allowance calculation. The Housing Authority's model Solar UA holds promise for affordable housing property owners that do not have access to cash flows, reserves, solar incentive programs or a research project like Beechwood. This model program may be one option for improving the effectiveness of UAs generally, to the benefit of property owners and their tenants.

Energy Upgrade California Program

Energy Upgrade California (EUC) is a statewide, rate-payer funded initiative that uses a comprehensive "whole buildings" approach to energy efficiency through technical assistance and incentives for energy efficiency upgrades at single- and multifamily buildings. The EUC program was in its initial pilot stage during the design phase of the Beechwood project and little was known of the program. The research team decided to investigate using the program early in the project. After working closely with EUC program staff the research team decided not to pursue involvement in the program or the incentives it provided for several reasons.

The energy modeling programs used by EUC were simplistic compared with those used by the Beechwood research team. This explains why the benefits of several energy-efficiency measures proposed by the project team were not recognized and credited by the EUC auditing team. In particular, the sealing and insulation of HVAC ducts in dropped-ceilings did not meet the minimum thresholds established by EUC. The duct replacement performed in this project was specific to the existing building and integrated duct chases and distribution system within the dropped ceiling. The simulations showed that the duct retrofit performed as if the ducts were moved to conditioned space. While the approach was novel, likely the main reason why EUC did not recognize it, it was proven to be very effective in reducing duct losses.

Additionally, the extent of testing and verification and the EUC-related costs that would be paid by LINC lacked the transparency of other similar programs, were much higher than expected, and the installations had to be completed by EUC-approved contractors, all of which were problematic for the LINC Housing Corporation. In addition, most of the EUC-approved contractors were unknown to LINC staff and the research team. Having faced these barriers early on in the process, the research team determined that projects much larger than the 30-unit retrofit at the Beechwood were a better fit for the EUC program. Coincidentally, upon completion of the original energy improvements that were not recognized by EUC audit staff the savings from duct sealing and insulation exceeded what the EUC program staff calculated.

LINC and the research team also planned on upgrading refrigerators with EUC or Southern California Edison (SCE) incentives, which require that the refrigerator being replaced was manufactured before 1999, which turned out not to be the case for those apartments. These EUC programmatic barriers can be resolved by changing the EUC program guidelines (if the program is still in existence at the time this report is published). For example, new EUC guidelines may include slightly newer refrigerators, and include more than one level of incentive based on the age and test results of refrigerators of fixed vintages.

The California Solar Initiative Multifamily Affordable Solar Housing Program

The project benefitted from incentives provided by the California Solar Initiative (CSI). CSI provides incentives for the installation of solar PV panels through its MASH program and solar thermal water heating systems through the CSI-Thermal program. The CSI program greatly improves the return on investment of solar systems by reducing the initial costs, and helps justify the installation of these systems.

MASH incentive levels vary based on the performance of the solar PV panels, including such factors as installation angle, tilt, and location rather than system capacity alone. This performance framework ensured that the Beechwood retrofit was optimally designed. The solar PV system does not have a method for LINC to directly recover the costs of the PV systems, but the incentive helped to appreciably reduce the first-cost impact. Because the Beechwood project incorporated a virtual net metering system the direct benefit of adding solar PV to the grid is delivered directly to tenants through bill credits (since the apartments are individually metered for electricity).

Due to the improper installation of virtual net metering protocols for the electricity generated at the Beechwood common areas, mainly the laundry room and community event rooms, LINC Community Housing was billed, rather than credited, for the cost of electricity generated by the new solar panels. This error did not affect tenant utility bills and it was resolved by contractors working with the utility. Because the Beechwood complex is individually-metered for electricity and master-metered for gas, the cost savings from the solar hot water system is credited directly to LINC Housing Corporation, who purchased the system. Unlike the installation of solar PV for electricity generation (which benefits the individual tenants), LINC will recover its solar hot water system costs through savings in natural gas in the future.

Overall, LINC and the research team faced minimal barriers with the CSI MASH program. The team found CSI staff to be efficient, helpful and timely, which may be due in part to the fact that the program has been around a while; the on-line application process is straightforward and easy to understand, and the fees (which are based on the size of the system) were straightforward. The only financial barrier related to this program cited by LINC Housing Corporation was the legal review required to resolve a budgeting issue with a MASH contractor who subcontracted out some of the work. This legal barrier can be resolved by simpler and shorter MASH-provided contract templates which protect the property owner and require minimal legal review.

Since this early work with MASH two years ago on the Beechwood project, LINC Housing Corporation has found the MASH program to be more cumbersome with other projects. The MASH program has generally become more inflexible. For example, simple requests for extensions due to common construction delays and project recalculations and costs now must go through approved contractors. This can result in delays as new people reevaluate and question original calculations that were previously approved. The research team believed that these “re-reviews” are unnecessarily burdensome. The construction process is characterized by weather and technical delays, so the solution to this barrier is to minimize extra review of calculations previously approved.

The Energy Savings and Assistance Program and Middle Income Direct install Program

The Energy Savings and Assistance Program (ESA) and Middle Income Direct Install programs provide no-cost, direct-install upgrades for income-qualifying customers. ESA provides installation of weatherization measures such as attic insulation, caulking, and weather stripping as well as low-flow shower heads and faucet aerators. The MIDI program, which extends benefits to those that do not meet ESA’s income requirements, also provides for attic insulation, low-flow shower heads and faucet aerators. Unlike ESA, MIDI provides duct sealing and testing, a major energy saving upgrade for many existing properties and an upgrade targeted in the planning stage of the project. The program is available to income-qualified renters and homeowners living in single-family and multifamily dwellings. Program services are provided by vendors authorized by and under contract to the local utility.

These two no-cost programs typically face barriers for eligible customers in multifamily properties for several reasons, but mainly because tenants must get written approval from the property owner for installation of the measures who must also coordinate the installations, while not benefitting directly from the savings. This was clearly not the case for the Beechwood project as the LINC Housing Corporation initiated and led the process on behalf of the tenants. The Beechwood project also piloted two specific program improvements. First, LINC received additional coordination and support from a Low Income Program Manager appointed by the utility who served as the main point of contact for the project. This assured that all available incentives that could be used were identified and deemed eligible during the project's early planning phases. Importantly, the Low Income Program Manager was able to perform some of the tasks that were normally performed by the property owner, thus freeing up time for the owner's staff. Secondarily, as an alternative to tenants being required to apply individually and online, the Beechwood project was able to design a valuable time-saving solution by using existing tenant data collected by the LINC Housing Corporation to demonstrate compliance with income qualifications. Because most of the Beechwood low-income tenants had limited to no Internet access, this alternative compliance approach further streamlined the application process. The research team found that many tenants lacked basic computer and Internet skills and services, which can slow down the retrofit process.

Through these two programs LINC Housing Corporation staff was required to work with multiple program-approved contractors, which was a notable barrier. LINC demands high quality work on their properties, and allowing multiple unknown contractors to install improvements required trust and new protocols within the company. This barrier was addressed through informal vetting of contractors, research on contractor references, careful examination of all installations and post-installation energy savings.

High Cost Barriers

Unusually high cost barriers were related to environmental mitigation and asbestos removal efforts in each Beechwood multifamily apartment. For example, the cost of asbestos abatement was nearly 70 percent of the cost of the efficiency retrofits; and the asbestos abatement was more than 40 percent of the total cost of the retrofit.

High first costs and the inability to recover these costs through financial mechanisms is a well-documented major barrier to LIMF housing retrofits. The Beechwood property contained asbestos, and it needed to be removed before the new energy efficiency improvements could be installed. Multifamily buildings built prior to the passage of the Comprehensive Environmental Response Compensation and Liability act of 1980 will typically contain asbestos as a building material. Asbestos, lead, and other toxic substances used in construction must be abated prior to any retrofits that might disturb the substance. These abatements can be very expensive. For Beechwood, asbestos abatement was required to cut an access hole into the dropped ceiling for replacement and insulation of ducts and the HVAC distribution box. The cost of this abatement was almost 70 percent of the cost of the efficiency improvements.

Asbestos is a known carcinogen contained in buildings and removal of asbestos can be cost-prohibitive. For example, total removal of asbestos from a 1,500 square foot home built prior to 1980 can cost $20,000 to $30,000. Asbestos was commonly used as a fire-proof insulating material in mastics used to seal joints in ducts and pipes, vermiculite attic insulation, ceiling and wall acoustical tiles, cement asbestos siding, and floor tiles (and floor tile adhesives). The Occupational Safety and Health Administration must be involved to ensure that all local regulations and requirements are followed during the removal process by licensed contractors.

On the Beechwood research project, the cost of asbestos abatement was nearly 70 percent of the cost of the efficiency retrofits; and the asbestos abatement was more than 40 percent of the total cost of the retrofit. The abatement costs were offset by the grant awarded for this research project. Without this grant funding asbestos abatement would likely have ruled out any retrofits requiring access to or work inside the apartments.

The research team also noticed a psychological barrier (and fear of the unknown) during the removal of the asbestos. Tenants were visibly concerned about exposure to the asbestos after watching licensed contractors appear on the Beechwood site in required hazardous material suits. Despite early educational efforts about asbestos, some tenants were still visibly scared about the future impacts of removing the asbestos from their apartments. This barrier can be addressed by advanced educational efforts for all impacted tenants, and by providing contact information to trusted sources who can answer tenant asbestos questions.

Technical Barriers

An unexpected barrier encountered by the team concerned data acquisition. Fewer data were ultimately collected than planned by the research team due to the limited geographic area covered by Wi-Fi, and the fact that the Wi-Fi units, and later hot spots purchased to replace the Wi-Fi units, were stolen, unplugged during the monitoring phase, or not allowed by the tenant. Essentially, the Beechwood Wi-Fi coverage was limited to common areas and would not cover the geographic region including the newly retrofitted apartments. The Wi-Fi units worked intermittently for the first three months, and then ceased to operate. To address this Wi-Fi limitation, the research team purchased individual hot spots for each apartment. A hotspot is a physical location where people may obtain Internet access, typically using Wi-Fi technology via a wireless local area network and using a router connected to an Internet Service Provider.

The team needed to return to Beechwood property and reinstall and set up these devices. A network of Wi-Fi hot spots were installed so that individual appliance use could be measured by the research team. In a number of instances during the project, these hot spot devices (as well as smart thermostats later described in the behavior barrier section) were removed (or reprogrammed in the case of smart thermostats) by tenants when they moved to new properties. Also, in some cases tenants refused to plug-in the new hot spots which effectively eliminated the opportunity to collect more specific energy data in some apartments during the monitoring phase. According to the LINC Housing Corporation, the complex experiences an annual 25 percent turnover of residents. Team members also had to re-educate tenants about the importance of not tampering with or removing equipment.

Prior to installation of the rooftop PVs on one of the buildings, the building's roof was supplemented with spray urethane foam insulation (SPF) and a weather-proof, wear-resistant solar roof. Before the SPF installation could be applied, there were preparations required, two of which ended up delaying the SFP application. One preparation was insulating the previously uninsulated supply and return ducts to the package-units located on the roof. The other was to determine whether the curbs supporting the HVAC package units on the roof were high enough to provide clearance between the ultimate height of the SPF and the bottom of the HVAC units to prevent the SPF from inadvertently adhering to the HVAC boxes, which would have become permanently affixed them to the SPF roof in their current locations and, going forward, be a huge barrier to any retrofit or repair work on the roof or on the HVAC units installed there. The HVAC curb minimum height requirements were met, and the HVAC ducts insulated. Technical barriers such as these are expected in many cases. One solution to alleviate the issue of stolen, unplugged, or never plugged in Wi-Fi and hot spot equipment is to incorporate a simple one-page contract between the multifamily housing owner and the tenant that requires or incentivizes tenants to plug-in or return monitoring equipment.

Behavioral and Informational Barriers

Behavioral and informational barriers occur due to lack of information or concern about energy use and its costs, what affects energy costs, and who is responsible for good energy behaviors and why. For example, at Beechwood, there was noteworthy “take back” or reduction in energy savings due to tenants using more energy because their costs are reduced, not recognizing or caring that those energy savings were paid for by the property owner

Some technology-savvy tenants reprogrammed their smart thermostats after the installation of the energy improvements and figured out a clever way to change passwords which invalidated the usefulness of what little monitoring data the team was able to collect. Therefore, their (new) thermostat settings impacted energy savings projections and invalidated expected differences and comparisons between the control group and the newly retrofitted apartments. This self-interested action is considered a behavioral issue. When forecasted versus achieved reductions are impacted negatively by behavioral actions like this, it is known as the rebound or “take back” effect. The team could not be sure what the exact impact on forecasted reductions was after these thermostats were reprogrammed intentionally by the tenants. The total microeconomic rebound is in most cases on the order of 20- to 40-percent when including all substitution and income effects and perhaps even including the embodied energy in the energy efficiency improvement (Gillingham, Rapson, and Wagner, 2015).

Imperfect information is one of the key barriers to energy efficiency savings. One of the most obvious information barriers is the performance of equipment and new technologies installed in LIMF apartments. The tenant generally gets one total electricity bill each month, so the performance of an individual device such as refrigerator, solar panels, or air conditioner is hard to separate. Since the tenant cannot see energy efficiency it is difficult to show them the value of improved efficiency of any particular electric appliance. The research team could address this barrier by more detailed educational efforts than the ones that were implemented at the Beechwood property, and by incentivizing tenants to leave the equipment alone. For example, a $25 gift certificate to a local retailer can be provided to the tenant after the monitoring period is complete. This simple solution would not improperly affect the energy behavior of the tenants, since it is rewarding them to simply not touch monitoring-related equipment. Several tenants commented to the research team about experiencing greater comfort inside their apartments after the energy improvements, but some of the Beechwood savings were definitely reversed by the rebound effect and behavioral changes. New, formal tenant guidelines can be written as a solution to this issue at Beechwood, and they can be personally discussed with each tenant. While time consuming, this method helps ensure that tenants know the energy use consequences of their actions. Furthermore, tenants can be more involved in the retrofits via an informal dashboard that be designed to allow tenants to “see” the results of their actions on a monthly basis.

Access to Tenant Work Space Barriers

These barriers were caused by a majority of stay-at-home tenants and varying tenant schedules at the Beechwood complex which made it more difficult to coordinate the timely installations of energy improvements

One key aspect of this research project was the team’s attempt to be fully aware and mindful of the customers. It is important for the property owner and tenants to both be pleased by the outcome of the retrofits. The team took extraordinary efforts to accommodate tenant schedules. Coordinating the retrofit work when the majority of LIMF tenants at the Beechwood property were stay-at-home tenants during the day provided many challenges to the research team. The team evaluated the possibility of doing all of the work at one time and temporarily moving all tenants at once versus doing the work on a unit-by-unit basis. The tenants were virtually of one voice that they would prefer to spend their nights and evenings in their own apartments and beds, and they were willing to stay out of their dwellings during the working hours during which the team required uninterrupted access.

The team developed a process to pack-up near the end of each of the four days that they or the asbestos specialist were working in the apartment so that the tenants could have dinner, sleep and breakfast in their own home. Fortunately, the asbestos abatement was completed in one long day, leaving the team three more to complete the retrofits in each apartment. They ran two teams, staggered by two days to be able to share certain individuals who were particularly good at some aspect of the work, as well as certain equipment, such as the insulation. This approach also required that the work be completed around existing furniture and other housing items and appliances, while avoiding doing any damage. The team worked hard to minimize the disruptions to tenant schedules; the same was not always true of the tenants. It was not uncommon for someone to need something from their apartment. The team did not make judgements; they allowed access if it were safe to do so, and gave the tenant a time to return when it would be safe. At the beginning of the project the team had no way to estimate and plan for tenants being home during the hours the team needed to be in the apartment, which was typically 8 a.m. to 5 p.m., sometimes a little more to satisfactorily store equipment and straighten and clean the areas where they were working in the apartments. One way to address this barrier in the future is to survey existing LIMF retrofit tenants to discover how long, and at what times, they expect to be in their apartments during the retrofit project. This would help project planners considerably.

Conclusions and Recommendations

Lessons learned relating to structuring LIMF financing and incentive programs during this multiyear research project and resulting recommendations include:

- UA reform is needed, and related tools such as the CUAC have considerable barriers that need to be addressed. The owner of Beechwood was unable to take advantage of the Los Angeles County UA because the allowance is/was too low and does not match the more extreme Lancaster climate. Existing utility allowances are too low in many counties, which can effectively nullify their use. In addition, the CUAC, while accurate, has major barriers that will prohibit widespread use of the tool until they are addressed. The tool is complex, and requires the purchase of two different software packages that are almost 10 years old. In addition, the CUAC software will not perform all of the calculations necessary for a CUAC approval, so extra Excel spreadsheets must be designed to accompany and supplement the CUAC modeling. This is a time-intensive process. Locating and obtaining personal technical assistance on the CUAC from the few available experts on the tool is challenging at best. Data collection for the CUAC is burdensome; some energy consultants who use CUAC regularly employ one FTE whose only job is to assemble the data needed for CUAC. These factors and others create barriers to CUAC and other UA applications. Calculating an accurate UA is a top priority early in the project development process; reform is needed to ensure that the numbers generated via the UA are accurate and close to the actual numbers that will be experienced throughout the project. The research team recommends close work with the State of California, HUD and CUAC experts to develop more meaningful and easier-to-use utility allowances and tools. It seems obvious that additional sub- or intra-county UAs, or property-or zip code specific UAs, would be more valuable to owners and tenants in the future.

- State run finance and incentive programs need more transparency, much easier access and regular evaluation to help ensure viability and value. The research team discovered that accessing state programs such as EUC were difficult, time-consuming and often confusing. The introductory process for the EUC needs to be simpler and faster, and the transparency of programs must be made clearer. The research team discovered while negotiating with EUC program staff that too much data collection was required too early, which resulted in wasted time. For example, the team was forced to turn over large amounts of data to the EUC staff and discovered too late in the process that the program would not fit Beechwood needs. Expensive post retrofit analysis and the costs associated with the prospective Beechwood analysis were largely ignored in early discussions with EUC program staff, yet made their way into later conversations. This caught members of the research team by surprise; more transparency would have been helpful. Essentially, the cost of these post-retrofit measurements was prohibitive and the team did not learn early enough about them. Getting to the right EUC program people required considerable time and team effort, involving cumulatively hundreds of hours. Contacting the EUC contractor, waiting for the contractor to appear, and then waiting further for the results of their analysis and recommendations can be a time-consuming, slow and patience-testing process.

  The research team discovered other programs that were helpful, but perhaps needed fine-tuning. The MASH program is one example. Strict contractor requirements during the project were burdensome, and background information on approved contractors was not as plentiful as desired by the owner. In addition, since installation of the retrofit improvements and the printing of this report LINC Housing Corporation staff notes while working on other similar projects that the MASH program is becoming more inflexible by requiring recalculations for previously approved changes that are due to delays in the construction schedule – expected delays often due to weather, schedule conflicts and contractor issues that are a well-known and accepted part of the business. The research team believes that these MASH program requirements should be relaxed to make it easier to do business with MASH rather than more difficult. The research team also advocates that program eligibility criteria be regularly evaluated and adjusted based on energy savings potential and the current LIMF market which may allow more appliances to be added to the list of measures covered by the program. For example, newer refrigerators – by only a few years – may be considered for the EUC program since a case can be made that the energy savings from these products are now cost-effective.

- Using a single point of contact for stacking financing and incentive programs can save time and improve efficiency. As noted previously, staff time dedicated to researching, finding, evaluating and comparing between programs, and ultimately arranging the final financing stack for the Beechwood project took considerable time. The research team took advantage of an offer from an investor-owned utility to provide a single point of contact also known as a "Low Income Program Manager." This person helped ensure that *all* available programs were evaluated thoroughly, and that the interplay and restrictions between the programs was clearly understood. Due to often complex eligibility requirements and the restrictions between using similar programs, the availability of one person with a comprehensive knowledge of these requirements was very beneficial to the research team. New program deadlines and launches occur throughout the year, so an expert is required. For example, the research team was interested in participating in an On Bill Financing (OBF) pilot, but the timing of the pilot did not match the project timeline. Had the research team known about the OBF pilot timing earlier from an expert, it may have been able to rearrange project deliverables to participate in the pilot. Using the utility-provided Low Income Program Manager provided an important, extra layer of assurance that all available programs were considered.
- Extra tenant educational efforts up-front can pay huge dividends at the end of the project. The research team discovered late that the majority of tenants were stay-at-home tenants. Had the team known this fact earlier, the work plan could have been adjusted as needed. Furthermore, 25 percent of the tenants moved on and vacated the retrofitted properties during the project, sometimes taking with them the hot spot equipment required for relaying important energy use data to the research team. A simply early, informal survey could have provided the team with this information and enabled the team to plan more effectively. The team thought that an informal contract between the tenants and the owner (perhaps a moral contract, not a financial contract),

which outlined clear expectations and roles during the project and the importance of obtaining accurate monitoring data, may have helped. At a minimum, it would have helped ensure that tenants knew the importance of not moving hot spot equipment and keeping thermostats programmed at the temperatures set by the research team. Tech-savvy tenants actually reprogrammed thermostats during the evaluation phase, compromising the integrity of the data. Setting the best policies to make sure LIMF tenants change their behavior to save more energy is no easy task. The research team believes that a small ($25-$50) gift card provided to the tenant after evaluative data is collected is one solution to this issue. Extra education to tenants regarding asbestos remediation to help calm any fears they may have and prepare them for contractors in hazardous material suits is also recommended with similar scoped projects.

- Perform advance work on Wi-Fi coverage to help guarantee that important evaluative data makes it to researchers. The research team discovered three months into the data evaluation phase that the Wi-Fi coverage was spotty and that data transmission was hindered by incomplete Wi-Fi coverage. If evaluation data is to be sent from future projects to evaluators remotely using Wi-Fi technology, as with the Beechwood project, it makes sense to test the Wi-Fi coverage early in the project to make sure that this potential technical barrier is addressed. Adding hot spot and other equipment later can be problematic. The research team believes that testing the property for needed and appropriate Wi-Fi coverage is an easy way to help guarantee that evaluative data gets to the researchers who need it.
- Joining any of the numerous LIMF financing collaboratives underway can save money and time. Solving the split incentive issue for LIMF housing requires many experts including developers, tenant advocacy groups, nongovernmental organizations, financing experts, state and federal government agencies, foundations and many others. To the extent possible researchers involved in future comparable projects should find and join any relevant LIMF housing collaboratives underway. For example, the “Energy Efficiency for All” collaborative (http://energyefficiencyforall.org/) is dedicated to linking the energy and housing sectors together to tap the benefits of energy efficiency for millions of low-income families (Energy Efficiency for All, 2017). They work with electric and gas utilities and their regulators interested in innovative energy efficiency program designs, and they advise housing finance agencies on best practices in building owner engagement and finance products. The project is a partnership of the Energy Foundation, Elevate Energy, National Housing Trust and Natural Resources Defense Council, and was made possible with funding support from The JPB Foundation. Collaboratives such as these offer off-budget technical and financial expertise that can make a sizable difference for some projects.

CHAPTER 10: Technology Transfer and Commercialization Plan

Public Technology Transfer

This project has received attention from both technical and general media. The project has been set as a model of near-ZNE retrofit for the low-income multifamily building segment. The following sections provide a list of articles and media reports about the project from different perspectives – green buildings, multifamily housing, low-income community, energy efficiency retrofit, occupant comfort improvement, and a low-cost and replicable solution for the building segment.

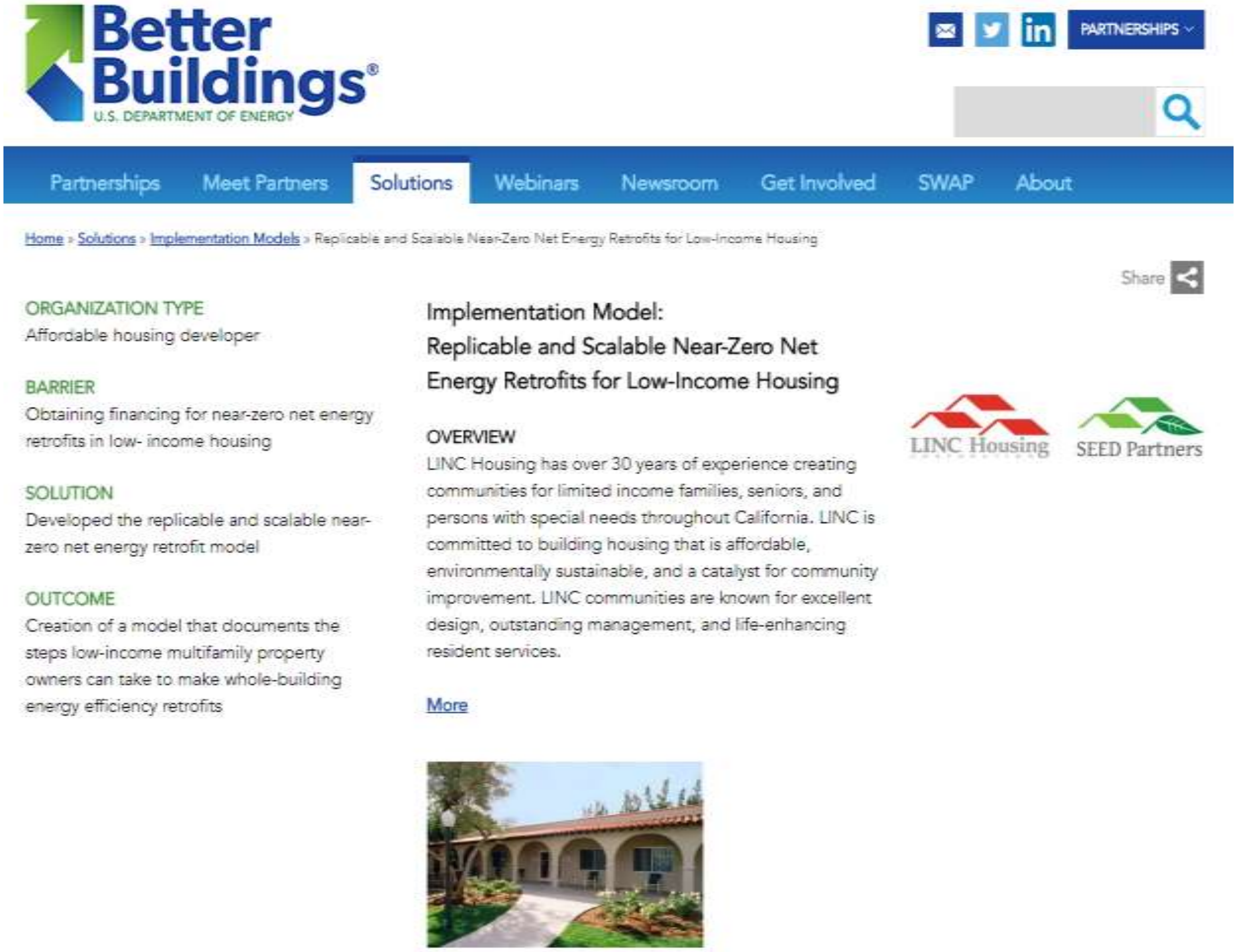
United States Department of Energy Better Buildings Highlights of Beechwood Project

The project has been listed on United States Department of Energy's Better Buildings permanent site, and received one of the top 10 views and an award as "Top-10 Solutions" in June 2016 (Figure 104 - Figure 107) (USDOE, 2016). The Better Buildings site provides an overview of the project, process of project design, outreach to residents, research results up-to-date and the methods used to conduct data monitoring and home energy management. The Better Buildings site has been following the progress of the project and continuously updating the contents as the team publishes technical articles and technology transfer materials to the public.

Figure 104: "Top-10 Solutions" of the U.S. Department of Energy Better Buildings (June 2016)

Source: United States Department of Energy

Figure 105: Project Description as an Implementation Model of "Top-10 Solutions"



Source: United States Department of Energy

Figure 106: Project on Department of Energy Better Buildings Twitter Page

Source: United States Department of Energy

Figure 107: Project on Electric Power Research Institute Twitter Page

Source: Electric Power Research Institute

Technology Transfer to Public on General Media

The project has received attention as it is the first near-zero net energy retrofit project in the low-income multifamily building segment.

USDOE's Better Buildings website has provided a thorough description of the projects including the latest research results based on the ACEEE paper published in August 2016. Better Buildings mentioned how the project started, the team members, and the objectives of this project including:

- Energy savings.
- Improved reliability and maintenance of systems.
- Cost savings and return on investment.
- Scalability into the multifamily housing market.
- Minimal disturbance of residents during construction.

Better Buildings provided the list of energy efficiency measures for this specific project, but also work related to similar low-rise wood frame garden apartments that are typical in California (Figure 108) (USDOE, 2016). The design also considered that the renovations would occur in occupied space, the accessibility limitations of the buildings, the potential for hazardous materials, and the cost effectiveness of each measure. In addition to the VERs measures, the team included on-site energy generation options in its analysis of options.

Better Buildings mentioned that the team calculated potential whole-building energy savings by simulating the impact of each proposed energy efficiency measure on energy use compared to the baseline. The results of this analysis provided the optimum cost-effective value for each measure and its impact on energy use. The team created small packages of VERs and simulated their impact on energy use to determine which set of efficiency measures would be most effective for the Village at Beechwood. The final package of VERs also included solar domestic hot water and solar photovoltaic systems for resident loads.

Better Buildings mentioned that the implementation scope, which covered 30 of the 100 units at the Beechwood project site and installed approximately 50 sensors to collect data and evaluate the effectiveness of each measure.

Figure 108: U.S. Department of Energy Better Buildings List the Selected Energy Efficiency Measures of Very Efficient Retrofit Package

	Measure	Feasibility
1	Thermostat Set Point Management: residents tend to keep their units very warm (many heated up to 75°F or higher)	Not easily enforceable
2	Increased Building Insulation: both wall and ceiling insulation were minimal and of poor quality installation	Neither practical nor cost-effective
3	Insulation of Hot Water System Underground Plumbing: system is uninsulated from the boilers to the building	Being explored to determine cost-effectiveness
4	Replacement of Laundry Equipment: runs at relatively low efficiency	Not cost-effective
5	Replacement of In-Unit Stoves and Ovens: old and run at low efficiencies	Will be evaluated on unit-by-unit basis
6	Lighting Retrofit: opportunities to replace all incandescent lighting with LEDs or fluorescents in both resident units and common areas of property	Feasible and leading measure candidates for VERs packages
7	Replace refrigerators beyond a certain age: Coinciding and coordinated with utility refrigerator replacement program	
8	Sealing of Envelope Leakage	
9	Sealing of Duct Leakage	
10	Sealing and Insulation of Building to Make Ducts in Conditioned Space, or Replacement and Heavy Insulation of Ducts	

Source: United States Department of Energy

Figure 109 to Figure 113 show media coverage for this project from local newspapers, MultifamilyBiz, Yahoo News, and Southern California Edison's website.

Figure 109: Antelope Valley Times Coverage (November 21, 2014)

The Antelope Valley Times

Your community. Your issues. Your news.

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$2.46M retrofit at Lancaster low-income apartments

by The AV Times Staff • November 21, 2014

Developers join resident children for a ceremonial tree planting in September to celebrate the start of the pilot project. The project, taking place at The Village at Beechwood in Lancaster, is backed by LINC Housing and SEED Partners with Electric Power Research Institute as the project lead, in collaboration with BiraEnergy, California Energy Commission, the U.S. Department of Housing and Urban Development, Southern California Gas Company, and Southern California Edison.

Source: Antelope Valley Times

Figure 110: Multifamily Biz Coverage

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First Affordable Housing Multifamily Near-Zero Net Energy Retrofit in California to Serve as Model

NOVEMBER 24, 2014

LANCASTER, CA - Work has started on the first near-zero net energy affordable multifamily retrofit in California. The $2.46 million sustainability retrofit project aims to bring energy inefficient, multifamily housing units at The Village at Beechwood (Lancaster, Calif.) to as near-zero net energy as possible, becoming a model for lowering energy and water costs for similar affordable housing communities nationwide.

"This work is important because we need to find a way to make multifamily housing more efficient," said Samara Larson, director of sustainability for LINC Housing and SEED Partners. "To date, there isn't clear data on how sustainability retrofits can be cost-effective, while reducing utility costs for owners and residents. This research project will give us that data so we can show the positive impact on costs and the environment."

Source: MultifamilyBiz

Figure 111: Yahoo Finance Coverage

MEDIA ADVISORY: $2.46 Million Sustainability Retrofit Begins at LINC Housing's Low-Income Apartment Community in Lancaster

September 15, 2014

LANCASTER, CA--(Marketwired - Sep 15, 2014) -

When: Monday, September 22, 2014 -- 3:30 to 5 p.m.

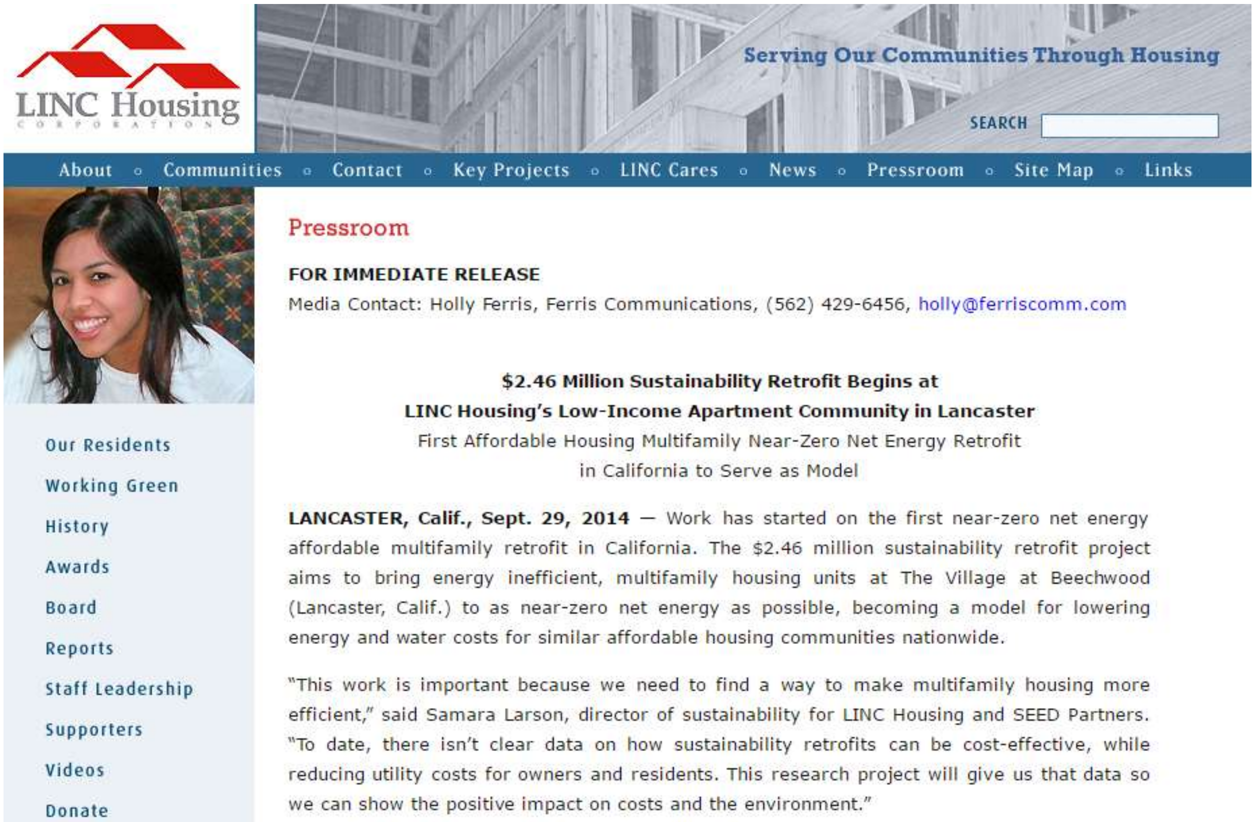
Where: The Village at Beechwood, 44063 Beech Avenue, Lancaster, CA 93534

What: The California Energy Commission and the U.S. Department of Housing and Urban Development have funded a pilot project that aims to retrofit low-income multifamily housing to be more energy and water efficient. The goal of this $2.46 million research project is to bring inefficient, multifamily housing units to as near-zero net energy as possible. This type of effort can become a model for lowering energy and water costs for similar affordable housing communities nationwide.

The Village at Beechwood is a 100-unit family community in Lancaster, Calif. SEED Partners is developing retrofit packages for individual units that are scalable and replicable. To date, two apartments have been completed with a net energy savings of about 70 percent. Now, the project has the green light to complete the additional 28 units in The Village at Beechwood research project.

Source: Yahoo Finance

Figure 112 : LINC Housing Pressroom and LinkedIn Page Coverage



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Serving Our Communities Through Housing

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Media Contact: Holly Ferris, Ferris Communications, (562) 429-6456, holly@ferriscomm.com

$2.46 Million Sustainability Retrofit Begins at
LINC Housing's Low-Income Apartment Community in Lancaster
First Affordable Housing Multifamily Near-Zero Net Energy Retrofit
in California to Serve as Model

LANCASTER, Calif., Sept. 29, 2014 — Work has started on the first near-zero net energy affordable multifamily retrofit in California. The $2.46 million sustainability retrofit project aims to bring energy inefficient, multifamily housing units at The Village at Beechwood (Lancaster, Calif.) to as near-zero net energy as possible, becoming a model for lowering energy and water costs for similar affordable housing communities nationwide.

"This work is important because we need to find a way to make multifamily housing more efficient," said Samara Larson, director of sustainability for LINC Housing and SEED Partners. "To date, there isn't clear data on how sustainability retrofits can be cost-effective, while reducing utility costs for owners and residents. This research project will give us that data so we can show the positive impact on costs and the environment."

Source: LINC Housing

Figure 113: Southern California Edison Website Coverage

Transforming Multi-Family Housing in Lancaster, Calif., to be ZNE

Are energy-smart ZNE technologies a good investment in low-income residential communities? Our utility, Southern California Edison, is teaming with several other companies to demonstrate that ZNE retrofits can be practical to install, replicable in quality, and successful in delivering energy savings and positive economic impacts for both property owners and residents. Retrofitting construction on 30 multi-family units in Lancaster, Calif., began in May 2015.

Source: Southern California Edison

Technology Transfer to Research and Development Community

Research Presented by American Council for an Energy-Efficient Economy

The American Council for an Energy-Efficient Economy (ACEEE) summer study on Energy Efficiency in Buildings is a biennial conference that gathers a diverse group of professionals to discuss the technological basis and practical implementation actions to reduce energy use and climate impacts associated with buildings. As of the date this report was prepared, these research results were accepted to publish on 18th ACEEE conferences in 2014 (Dutta, Hammon, Narayanamurthy, 2014) and 19th ACEEE conferences in 2016 (Hammon-Hogan, Larson, and Zhao, et al, 2016). (Figure 114 - Figure 115).

Figure 114: Research Paper Presented at 2014 American Council for an Energy-Efficient Economy Summer Study on Buildings

Replicable and Scalable Near-Zero Net Energy Retrofits for Low-Income Housing

Tushar R. Dutta, LINC Housing Corporation
Rob Hammon, BIRAenergy
Ram Narayanamurthy, Electric Power Research Institute

ABSTRACT

LINC Housing Corporation (with support from Kango Development) has partnered with Electric Power Research Institute (EPRI) and BIRAenergy to develop, demonstrate, and document the implementation of deep, near-zero energy (near-ZNE) retrofits of low-income multifamily properties in California, through a comprehensive turnkey approach including:

- Cost effective Very Efficient Retrofit (VERs) packages
- Rigorous monitoring to validate actual savings
- Financial tools
- One-stop delivery models
- Resident education

The VERs will be implemented at The Village at Beechwood, a 100-unit low-income property owned by LINC in Lancaster, California. The team is designing and evaluating VERs for different building and unit types. An estimated 50 sensors will be installed to collect data to evaluate each VER. Energy and demand savings will be facilitated through training of residents, providing each unit with a Home Energy Meter System (HEM) that is coupled to a "smart" electrical panel and smart meter. Each retrofit will include Demand Response appliances that are controlled by the HEM and the utility.

The effort launched in October 2013. The PIER Beechwood Team ("Team") is developing a baseline and VERs with construction slated for June-November of 2014. The presentation of this paper will likely reflect activities through the construction period. One year of post-retrofit energy data will be collected. LINC's Resident Services team will work intensively with residents throughout the process to encourage energy-wise behavior. The goal is to demonstrate scalable, replicable models and provide tools for implementation to multifamily property owners.[1]

Source: Electric Power Research Institute

Figure 115: Research Paper presented at 2016 American Council for an Energy-Efficient Economy Summer Study on Buildings

Replicable and Scalable Near-Zero Net Energy Retrofits for Low-Income Housing

Ian Hammon-Hogan, BIRAenergy
Samara Larson, LINC Housing Corporation
Peng Zhao, Electric Power Research Institute
Ron Kliewer, Southern California Edison
Ram Narayanamurthy, Electric Power Research Institute

ABSTRACT

LINC Housing Corporation partnered with Electric Power Research Institute, BIRAenergy, Southern California Edison and Southern California Gas Company to develop, demonstrate, and document the implementation of deep, near-zero energy retrofits in low-income multifamily properties in California, through a comprehensive turnkey approach including:

- Cost-effective Very Efficient Retrofits (VERs)
- Rigorous monitoring to validate actual savings
- One-stop delivery models
- Resident education

The VERs were implemented at The Village at Beechwood, a 100-unit low-income property owned by LINC in Lancaster. The team designed solutions for and evaluated different building and unit types. Energy and demand savings were facilitated through resident engagement and installation of smart thermostats.

Launched in October 2013, the PIER Beechwood Team developed a baseline and VERs, with construction starting in 2015. Construction in the community building and implementation of emerging technologies will continue into 2016, as well as monitoring activities. One year of post-retrofit energy data is being collected from resident units. LINC's Resident Services team will work with residents throughout the process to encourage energy-wise behavior. This presentation will update initial findings presented in 2014 (Dutta, Hammon, and Narayanamurthy 2014), comparing design goals to actual results with lessons learned through the process. Presentation content will range from test data to resident interviews. The project goal was to demonstrate scalable, replicable models and provide tools for implementation to multifamily property owners. Real upgrade costs combined with estimated utility-bill savings represents a 20-year simple payoff, suggesting that this process could be scaled and maintain cost-effectiveness in the absence of grant funding.

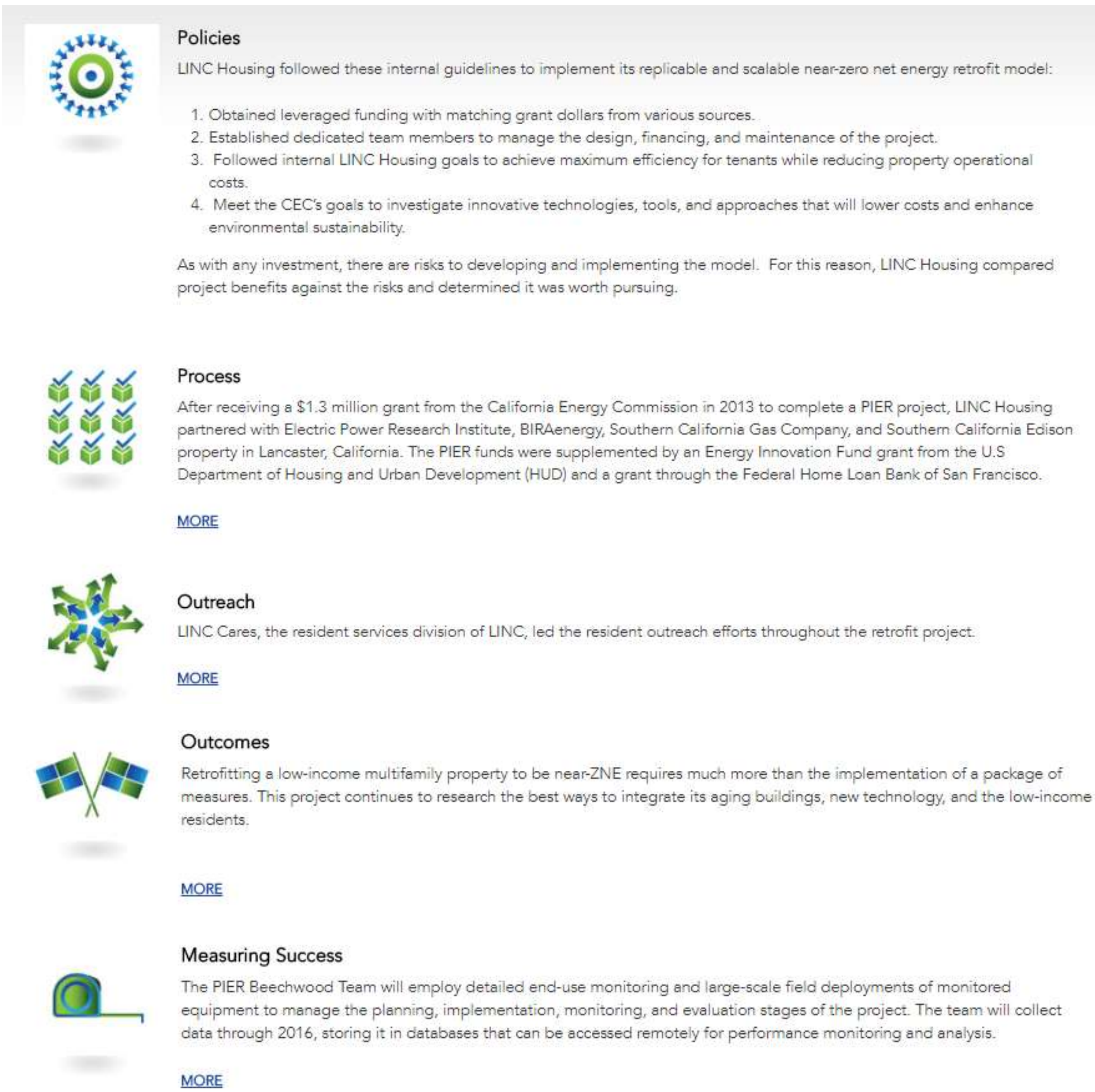
Source: Electric Power Research Institute

Research Results Published by Department of Energy Better Buildings

USDOE's Better Buildings website has provided a thorough description of the projects including the latest research results based on the two ACEEE papers that were published in 2014 and 2016. The Better Buildings site understands that retrofitting a low-income multifamily property to be near-ZNE requires much more than the implementation of a package of measures. It also requires research and development effort to integrate its aging buildings, new technology, and scheduling work in harmony with the low-income residents to accomplish the work with as little interruption of their daily lives as possible.

Better Buildings used research results published in ACEEE conference to showcase the energy efficiency improvement in those retrofitted apartments. Better Buildings mentioned that the focus of retrofits in these apartments was on weather sealing the apartments, insulating ceiling spaces, and sealing and insulating ducts that distribute air from the roof-mounted HVAC to the occupied spaces within the units. Better Buildings agreed that all of these measures increased the effectiveness and efficiency of the cooling system without replacing the units, and allowed the units to perform more efficiently during the hottest months. Refer to Figure 116, clicking the "More" button on the website expands detailed descriptions of each section.

Figure 116: Research Results Posted on Better Buildings



Policies

LINC Housing followed these internal guidelines to implement its replicable and scalable near-zero net energy retrofit model:

1. Obtained leveraged funding with matching grant dollars from various sources.
2. Established dedicated team members to manage the design, financing, and maintenance of the project.
3. Followed internal LINC Housing goals to achieve maximum efficiency for tenants while reducing property operational costs.
4. Meet the CEC's goals to investigate innovative technologies, tools, and approaches that will lower costs and enhance environmental sustainability.

As with any investment, there are risks to developing and implementing the model. For this reason, LINC Housing compared project benefits against the risks and determined it was worth pursuing.

Process

After receiving a $1.3 million grant from the California Energy Commission in 2013 to complete a PIER project, LINC Housing partnered with Electric Power Research Institute, BIRAenergy, Southern California Gas Company, and Southern California Edison property in Lancaster, California. The PIER funds were supplemented by an Energy Innovation Fund grant from the U.S Department of Housing and Urban Development (HUD) and a grant through the Federal Home Loan Bank of San Francisco.

MORE

Outreach

LINC Cares, the resident services division of LINC, led the resident outreach efforts throughout the retrofit project.

MORE

Outcomes

Retrofitting a low-income multifamily property to be near-ZNE requires much more than the implementation of a package of measures. This project continues to research the best ways to integrate its aging buildings, new technology, and the low-income residents.

MORE

Measuring Success

The PIER Beechwood Team will employ detailed end-use monitoring and large-scale field deployments of monitored equipment to manage the planning, implementation, monitoring, and evaluation stages of the project. The team will collect data through 2016, storing it in databases that can be accessed remotely for performance monitoring and analysis.

MORE

Source: United States Department of Energy

Presentations on Low-Income Multi-Family Building Segment by LINC Housing

LINC Housing presented experiences and lessons learned from this project at various webinars and meetings. The PowerPoint presentation slides (beginning with Figure 117) covered information on experience gained from this project, energy efficiency measures, financing and incentives, the retrofitting process, energy consumption, water use, energy audits, retrocommissioning, and the fundamental question of whether investing in "green" is a good choice for multifamily buildings. This presentation was useful for technology transfer to the low-income multifamily community for education, training and customer engagement purposes.

Figure 117: Topics of LINC Housing Presentations on Energy Management in Multifamily Housing

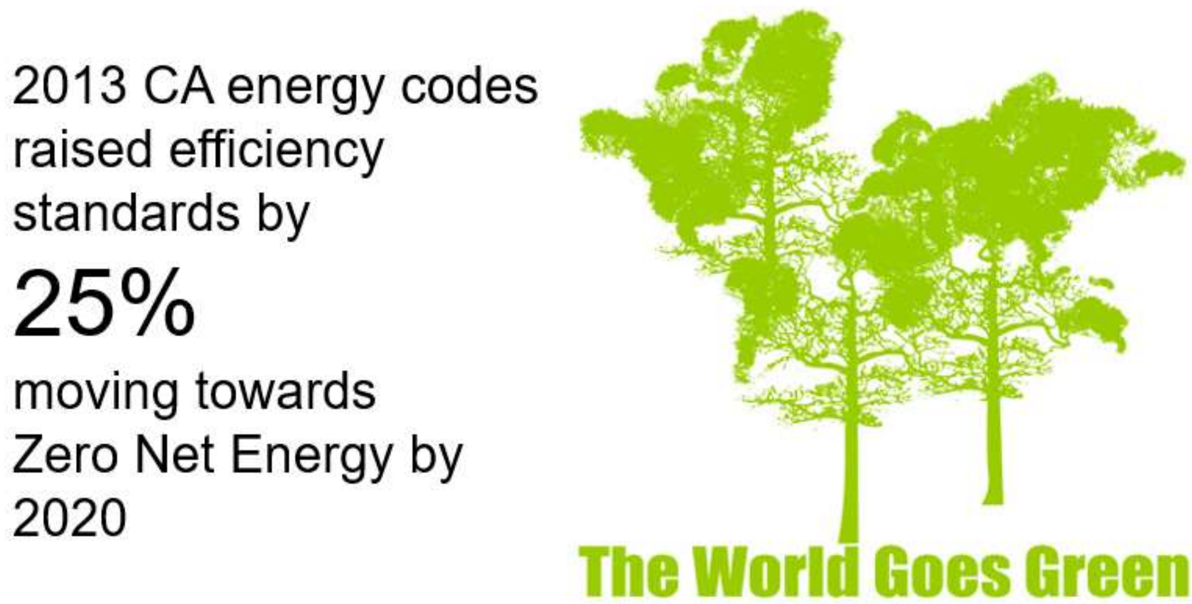
Source: LINC Housing

The presenter stated, "When we first started this work, there was a lot of discussion about whether building green was truly worth the investment. Those who jumped in at the start took a risk as to whether it would pay off for them the way their designers and consultants promised it would." "Now, there's enough stock of buildings in the market that the value of the green building and its impacts can be shown – on asset values, rental rates, vacancies, and of course, on operating costs."

The presenter also noted that "these results come from a variety of sources – there have been studies in many markets – commercial and single family, as well as multifamily, in various part of the country. Repeatedly, they show that green buildings have value – to the people who buy and sell them, live in them, work in them." "People are more productive, more comfortable, and perhaps important to many of you today, green buildings also are more cost effective in the long run to operate."

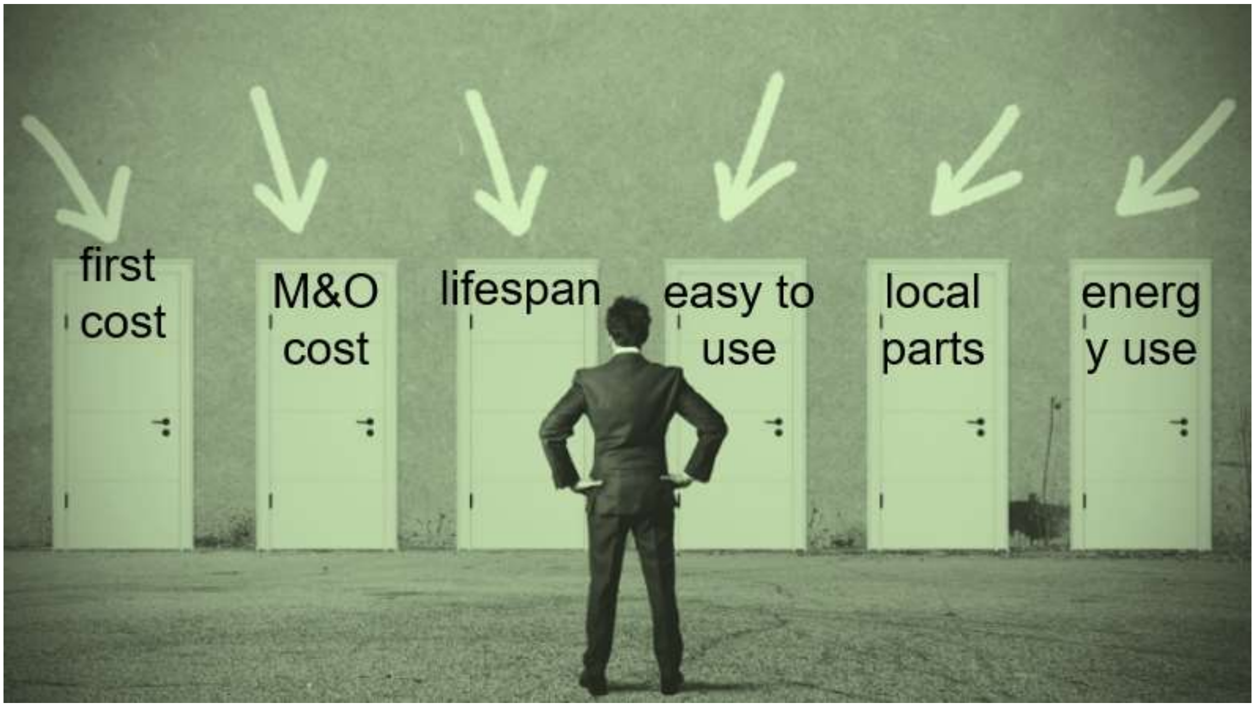
The presenter also noted the California ZNE goals to reach all new residential buildings to be ZNE by 2020 and all new commercial buildings to be ZNE by 2030 (Figure 118 - Figure 119).

Figure 118: Impact of California Codes



Source: LINC Housing

Figure 119: Different Aspects Affecting Zero Net Energy Designs and Decisions



Source: LINC Housing

The presenter mentioned that selecting the energy efficient measures into the retrofit package depends on the choice of the goal. She explained, "If you decide to install a solar hot water system or a tankless hot water system, both will provide energy savings. But each has a different long term impact in terms of maintenance, life span, overall energy costs – it may depend on whether you've set a goal of net zero energy, how you've decided to recover costs for water heating on that property, what your space needs are, how you plan to use your roof space. The upfront incentives for each are quite different. Both these things can meet the energy code requirements for efficient water heating, probably within the budget you've established. But each of them have very different results for all of these other goals."

The presenter mentioned that one of the things to look at on a project relates more to the financing side of the project. Many people tailor their choice of energy efficiency measures to take maximum advantage of the tax credits that may be available. Tax credits are an ever-changing market, but the presenter identified two of the most commonly used at the time: Energy Efficient Home Credit and Solar Investment Tax Credit (Figure 120).

Figure 120: Methods to Financing Zero Net Energy Projects

Source: LINC Housing

The presenter explained that the Energy Efficient Home Credit provides a financial incentive for properties that choose to build more efficiently than a minimum standard. This a federal tax credit, so the comparison is to the 2006 International Energy Conservation Code. Working from the start with the design team, particularly the energy engineer, to align this requirement with the California codes allows property owners to identify adjustments needed to meet this requirement and compare the financial benefit (both from the tax credit and any efficiency savings) to the construction cost increase related to added measures.

The presenter explained that the Solar Investment Tax Credit, also referred to as an energy tax credit, is currently worth about 30 percent of the "energy asset" costs. It can be used for system installation on existing buildings as well as new. This credit allows for a more straightforward analysis of the benefits. Many owners use this to install solar PV systems to reduce the electricity costs for the building common areas, but as the cost of solar has come down, some owners have installed systems that provide a credit to tenant bills and used this to justify marginally higher rents in competitive markets. With the increasing cost of electricity, this may become a more attractive amenity for some.

Irrigation water uses accounts for 50 percent of water use in low-rise multifamily properties. The presenter mentioned that irrigation water is also nearly half of the utility cost paid by the owner as well, so it can be a big potential for savings (Figure 121).

Figure 121: Impact of Water Use

Source: LINC Housing

One area many people overlook for water reduction is washing machines (Figure 122). The presenter mentioned that if the community has centralized laundry rooms, even if the supply and maintenance of these machines is outsourced, the utility costs are typically paid under the property's operating costs. Requiring vendors to supply energy efficient equipment will help keep the costs down, both for the water, and the energy to heat the water.

Figure 122: Water Use in Washing Machines

Source: LINC Housing

The presenter mentioned that one way to take this a step further is to consider encouraging cold water washing to reduce energy use. A study conducted by the Alliance to Save Energy showed that in locations where a there was a price variation for cold, warm and hot water washing, with the cheapest price offered for the cold water wash, energy use could be reduced by as much as 30 percent.

The presenter mentioned that energy and insurance are the two biggest costs most owners have in their budget that they cannot directly control, and when hit with a price increase, they often have to scramble to make up the difference with cost reductions elsewhere.

Commercial electricity rates increased an average of more than 7 percent just from 2013 to 2014. Natural gas pricing has increased at about 5 percent per year, and these trends are expected to continue with no drop off in sight (Figure 123).

Figure 123: Cost of Energy

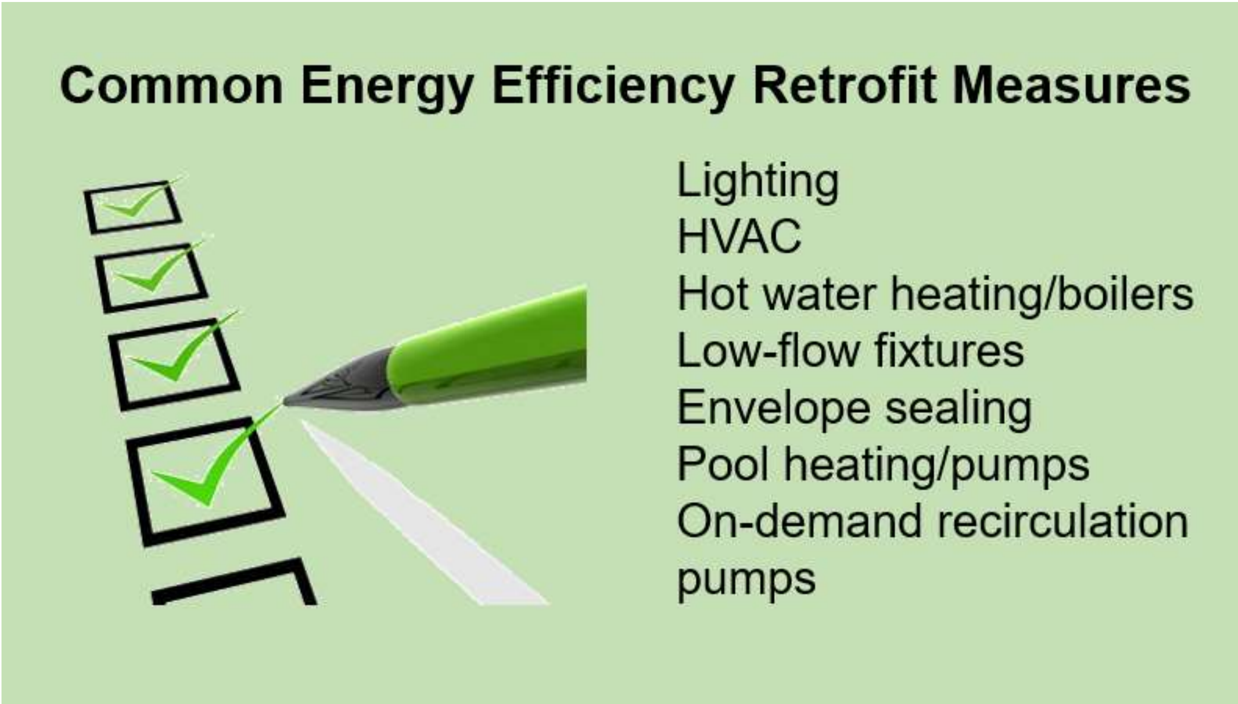
Source: LINC Housing

Listed are some common energy efficiency retrofit measures, including lighting, HVAC, water heating, envelope sealing, pool pumps and recirculation pumps (Figure 124). An energy auditor can evaluate the property or portfolio to determine where efficiency improvement opportunities are and choose the suitable energy efficiency measures. Some projects, such as lighting retrofits and pump upgrades, typically have very short payback and high return on investment with minimal upfront capital required. The challenge with these projects can be getting an owner's interest and attention to pursue the work. Often, the best approach can be to look at a portfolio-wide solution, to maximize the returns once the project has been approved.

The presenter mentioned that depending on how similar building types and systems are, it may be more effective to approach projects on a systems basis across a portfolio, for example replacing all of the hot water boilers with high efficiency boilers, to gain economies of scale. Or one could choose to look at all the improvements at one property where energy costs are noticeably higher than any other property. Completing an audit can provide the information needed to make an informed decision.

The presenter mentioned that there are different levels of audits, the simplest ones will highlight straightforward opportunities, providing only general information on costs and savings. Deeper audits will explore the projects more thoroughly, providing more detailed information about costs and expected returns, often including information on possible utility rebates and incentives. These audits will cost a little more and take more time to complete in return for delivering more comprehensive information.

Figure 124: Common Energy Efficiency Measures



Source: LINC Housing

Another opportunity more people are taking advantage of is retrocommissioning, or some people referred to as "building re-tuning" (Figure 125). Some say that up to 20 percent of the energy used in commercial buildings is wasted because of improper operations. Building re-tuning provides a way to have an immediate impact, especially in the often-overlooked small building market, which includes many multifamily buildings. Small buildings are usually those under 100,000 square feet that frequently do not have any centralized building automation systems. These buildings often have package units for heating and cooling, and are controlled by zone thermostats.

Figure 125: Building Retuning

Source: LINC Housing

The presenter mentioned that there are rebates and incentives available to offset the cost of energy efficiency upgrades (Figure 126) so one should contact the local utility company or check their website prior to beginning a project. Some utility programs may offer an audit to help evaluate the potential projects. The programs vary, and will change over time, so it is important to check back regularly. Some programs are based on specific equipment replacements, and others are whole building approaches that will provide an incentive based on the total savings achieved. It can be worthwhile to find out what is available, as some programs can cover a large part of the incremental cost increase between standard equipment and more efficient equipment.

New programs are being developed to help pay for energy efficiency improvements. Two more recent developments are on-bill repayment and Property Assessed Clean Energy (PACE). On-bill repayment allows customers to borrow money for efficiency projects and repay it through their utility bill. The intent is that the savings achieved from the improvement will be put towards the payment, resulting in "bill neutrality," essentially no increase in the monthly bill payment.

PACE is another alternative financing structure. Using approved lending programs, these loans are repaid through an annual assessment on the project's property tax bills. Proceeds of the loan can be used for any energy efficiency upgrades or renewable energy installations, and the approval process is designed to consider the savings achieved by the improvements.

Figure 126: Financial Incentives

Source: LINC Housing

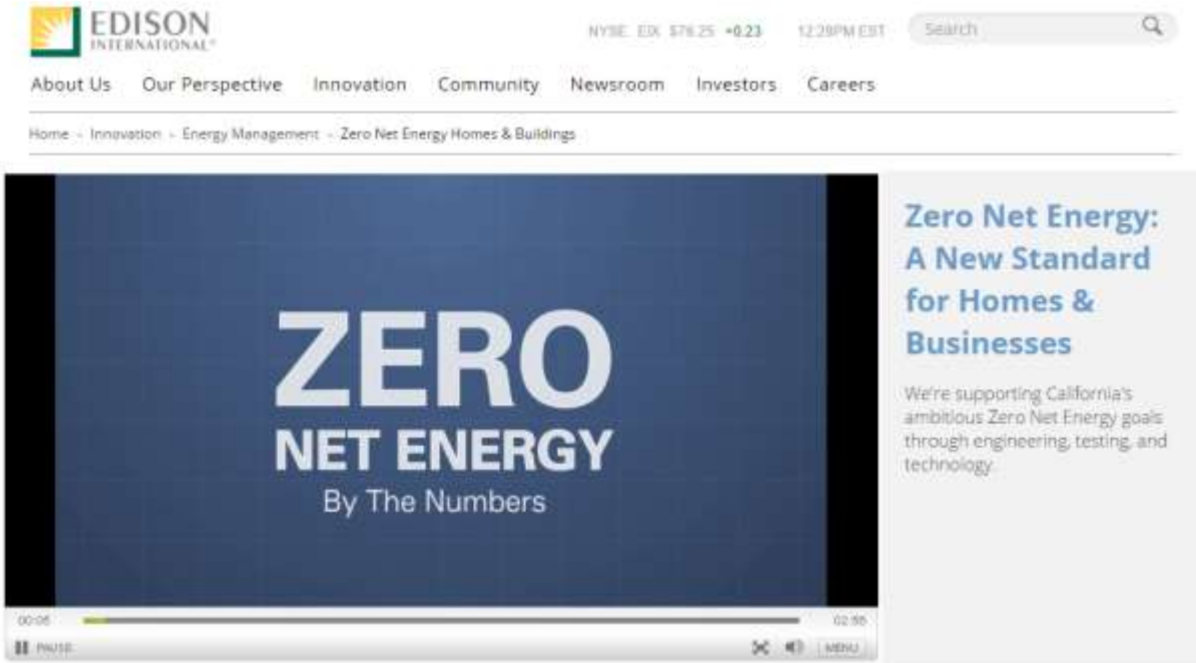
Some mortgage lenders have also designed products to allow for additional borrowing capacity when a property is refinanced to encourage owners to incorporate energy efficiency projects into the property.

Regardless of financing structure, the estimate of savings will be a key point of discussion with any lender. Typically, something less than 100 percent of estimated savings will be assumed for the potential repayment.

Technology Transfer to Utility Industry

SCE has devoted a great deal of effort to ZNE buildings. SCE has a permanent website that lists all ZNE and near-ZNE projects within its territory, including this project (Southern California Edison, 2017). These projects serve as utility research and field study pilot projects to shape the development of California's ZNE building codes by providing technical, engineering and planning support, as well as electricity-usage monitoring to ZNE projects. The pilot projects also help enhance the utilities' expertise, ensuring that all the renewable energy and energy-efficiency components work together to deliver ZNE-level performance to meet California's ZNE goals. SCE's ZNE projects have been mainly focused on single-family homes, residential communities, multifamily developments, school and community college buildings, and a low-rise commercial ZNE, most of which are all listed on the permanent website. The ZNE "By The Numbers" video showcases several of SCE's ZNE efforts, including this multifamily project in Lancaster, CA (Figure 127). Figure 127 to Figure 132 are the materials posted on SCE's site.

Figure 127: Southern California Edison Permanent Website on Zero Net Energy Including Project



Source: Southern California Edison

Figure 128: Southern California Edison Description of the Village at Beechwood Site

Source: Southern California Edison

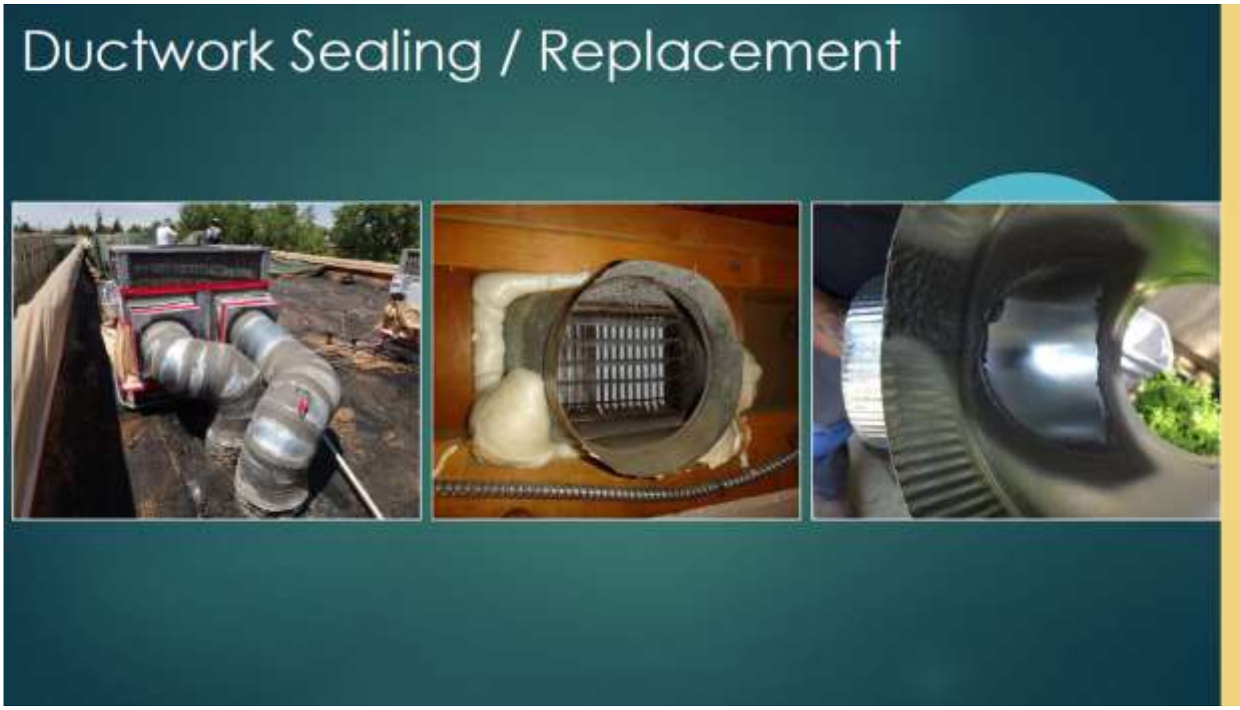
Figure 129: The Project Team Introduced by Southern California Edison

Source: Southern California Edison

Figure 130: Advanced Building Diagnostics Posted on Southern California Edison Site

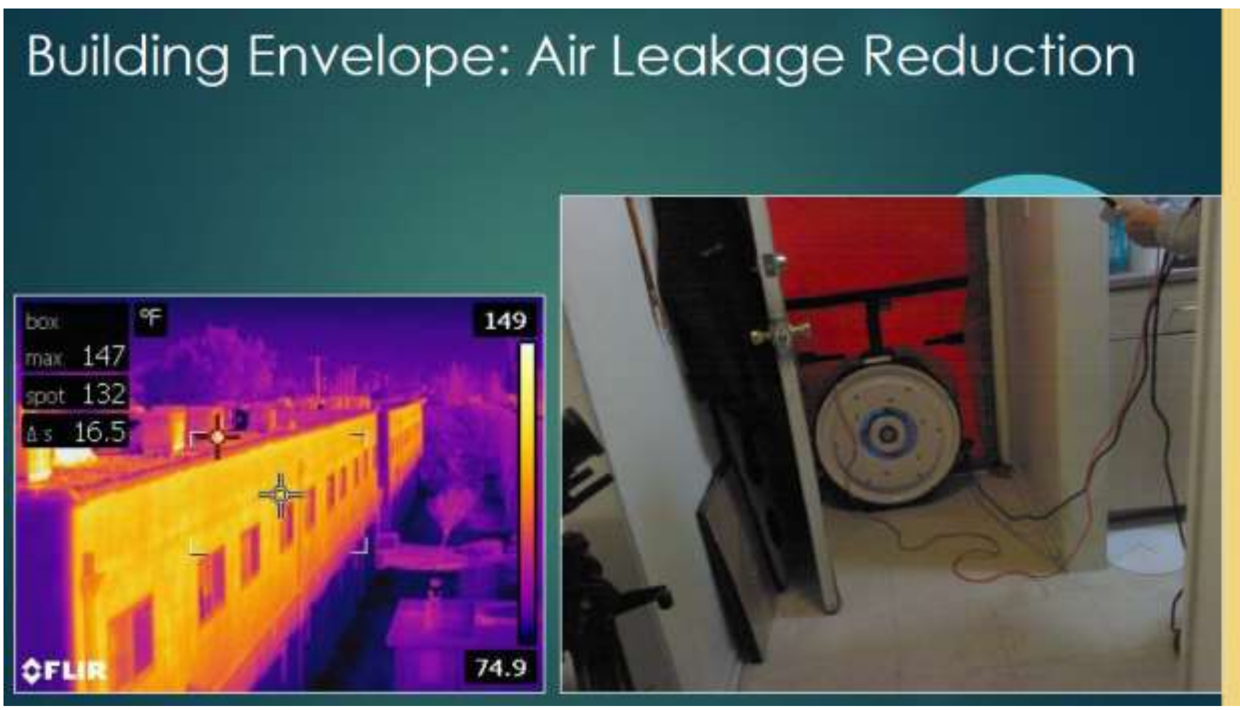
Source: Southern California Edison

Figure 131: Ductwork Sealing and Replacement Posted Southern California Edison Site



Source: Southern California Edison

Figure 132: Building Envelope Improvement Posted on Southern California Edison Site



Source: Southern California Edison

Benefits to California Ratepayers

The energy benefits of the project were consistent with the estimated and proposed energy benefits. The average electric energy use for the apartments in 2013 was about 22.5 kWh/day and the net reduction from energy efficiency equated to 5 kWh/day/unit. Given California has about 7 million apartment residents, the potential for electric energy savings equates to 12.75 GWh annual savings.

The natural gas energy use reduction at the individual unit level was of the order of 10 percent and the water heating reduction was 58 percent at the community scale. At the community scale, this translates to approximately a reduction of 28 percent in gas usage, or about 14,400 therms annually (144 Therms/unit). Scaling this to the entire state, the net potential for energy use reductions is 1 billion therms in multifamily properties alone. Combining the gas and electric benefits, the potential benefit for the state of California in terms of greenhouse gas reduction is 6,200,000 metric tons of CO_2 reduction, primarily from the gas savings.

There are other benefits beyond the energy and environmental benefits that accrue to occupants and tenants of low-income communities. Improvement in quality of life for occupants in these communities should be considered as a key non-energy benefit of energy efficiency upgrades. In one example, a mother referenced how better indoor temperature and humidity control through better insulation could help with her daughter's nosebleeds. In another, an occupant indicated how his comfort was substantially improved with the implementation of the measures and the smart thermostats. As part of the project, the job training provided for solar installation improved the morale and future job prospects for these families.

In summary, the team encourages consideration of both energy and non-energy benefits as part of future work on affordable income communities. The long-term benefits of this implementation including better health, cost savings and economic opportunities to low-income tenants. Incentives for energy efficiency are necessary not just to tenants, but also to property owners who will need to invest substantial money, time, and effort in implementing these measures.

CHAPTER 11: Lessons Learned and Conclusions

Lessons Learned

Installation

One of the most important lessons learned was that when a specialty contractor is chosen to perform the work, technicians actually performing the work must have the full scope of work in their possession, laid out in the order in which it needs to be performed. They also need to have the training to be able to understand the concepts, tools and materials required to complete the tasks. It is not enough that the managers who bid the job understand the work and the nuances required to skillfully complete the job; this information needs to be passed on to the field crews. A recurring theme on many projects is field crews attempting to perform their work without having critical information needed to be successful. This must be rectified if projects requiring specialty skills and procedures are going to be successfully completed. This is particularly important with the less understood and less widely practiced energy efficiency trades that work on existing buildings, retrofitting occupied buildings.

Another item that can cost a project dearly in both time and cost overruns is not having qualified construction management onsite at important project junctures. While construction work is underway, it is imperative that someone is onsite while all critical work is being performed. This person should know how work should be performed and, if it is not being performed correctly, should have the authority to correct the situation or at least document conditions and report the findings immediately. Examples of these critical times are when new phases of the work are being started, when multiple trades are onsite simultaneously, and especially when multiple trades have tasks that take place in/ on the same building and may touch the same equipment or part of the building/ grounds.

Other lessons learned include:

- Perform a potential hazards survey as part of the initial site survey when considering a location for a project. Lead paint, asbestos, mold, etc. can greatly increase costs. However, on the other hand, Beechwood is an example of real world conditions that exist in many older buildings that are in dire need of energy upgrades.
- For buildings constructed prior to early 1980's, be aware of asbestos. Asbestos abatement is very expensive and weighs heavily on cost-effectiveness. Before initiating any kind of efficiency upgrade analyses determine whether any asbestos is present, and if so whether it can be avoided in the application of any upgrades, and/or other ways to mitigate asbestos and costs of mitigation.

- In the project planning process, budget for and include performing a pilot of the planned installations. Pilots provide opportunities to improve installation methods and may provide opportunities for improvements that were unanticipated.
- Set up the project such that only small budget adjustments are allowed post-pilot. Set some small percentage of the total budget as the maximum allowed; if more than the fixed percentage is requested by the subcontractor, the property owner can opt to rebid the main contract. If the contractor opts to rebid, the job should be allowed to be rebid among other contractors; make sure the contractor knows that rebidding will be open.
- Be mindful of the potential for opportunities for improvement made available by other upgrades. This is most important during pilots, but could happen at earlier research phases and/or later construction stages.
- Hire the best, rather than the least-expensive, contractors. The difference in quality will more than make up for the cost with improved energy savings from work done well, compared with work done only adequately.
- Monitor progress. Every contractor should be closely and carefully monitored by a knowledgeable party associated with the property owner. Almost every contractor needs to be monitored to maintain the quality of the work that they chose to bid. Also, do not let the contractor squeeze out of work they included in their bid. A knowledgeable subcontractor who performs quality work will bid the work properly in the first place.

Simulations

- Verified a robust method.
- Found that it is best if some of the final review time is done by a second modeler.
  - Modeling is almost like big data and so it is highly error prone. At least one mistake per model is expected without a second eye to check the data.

Project Management

- Performing as much site work as possible simultaneously could reduce project overhead and contractor’s bid prices, thus shortening the overall timeline of the project as well.
- Vampire load in induction cooktops.
- Heat Pumps heat strips can turn on at strange temperatures.
- Hard to get a team that is accustomed to 5 ACH50 to make 3.5ACH50.
- Keep on top of the local city/ county utility status. Lancaster switched away from SCE as the power provider partway through the project and caused billing issues for the tenants and headaches for the management as well.
- Always give as much notice to the site manager as possible when scheduling work and site visits by the project team members.

Economics

- People will pay for efficiency as a value-added feature.

Benefits

- When energy upgrades are performed on multifamily buildings, other non-energy benefits are realized as well. For example, indoor air quality can improve, tenant satisfaction can increase dramatically and tenant turnover may decrease. Property values may increase.

Tech Transfer

- Additional effort is needed on educating tenants on how to use the smart thermostats needs more effort. Very few tenants understand the capabilities of their thermostats, much less how to use them.
- Educate the maintenance crews about the upkeep of the various types of equipment.
- Educate the tenants (and all project participants), that ZNE does NOT mean there will be no utility bills.

Conclusions

Based on this research, it continues to be challenging to implement energy efficiency retrofits in existing low-income apartments achieving a favorable return on investment without some rebates, incentives, or financial assistance. A LIMF owner is hard pressed to make the investment required for energy efficiency improvements without financial help, especially for older units that are prone to abatement issues such as asbestos, lead paint or mold. To mitigate these hazards adds substantial cost to the retrofits, substantially increasing the payback period.

Due to the complexity of funding sources for energy efficiency measures, PV and related items, there is no single “one size fits all” scalable financial solution for funding these types of retrofit projects, though the team has identified in this report that successful ZNE retrofits can be financed. If financing for energy efficiency measures is not available in the amount needed to install a full package of measures, savings from a portion of efficiency measures could help support additional measures later.

The measures chosen must make sense in several ways. The shortest return on investment is always a high priority. However, the most desirable measures would be those that not only save energy, but also add value to the occupants lives through better indoor air quality, more comfortable living space, or added property and aesthetic value. Some measures can be included in a package of measures that may not make sense when installed alone, but are more effective as a part of a suite of measures. An example of this is adding insulation without air sealing the building. By adding the air sealing measure to the insulation, the insulation performance noticeably increases.

LINC Housing has followed up the project with a large-scale deployment of nearly 1.5 MW of solar through power purchase agreements in six of their properties. The deployment of solar will potentially reduce energy bills for tenants. However, lack of a financing model for energy efficiency prevents scaling of EE measurers similar to solar. Financial institutions such as banks and third party financiers do not yet trust energy efficiency to consistently deliver returns over the long term. The team recommends future research initiatives focused on developing models substantiated by data that would increase the confidence of financial institutions in energy efficiency savings and thus unlock the capital required for scaling near-ZNE retrofits in low-income housing.

LIST OF ACRONYMS

Term	Definition
AC	Air conditioning
ACEEE	American Council for an Energy Efficient Economy
ACH	Air change per hour (commonly followed by number referring to pressure in Pascals at which measurements are made)
AFUE	Annual fuel utilization efficiency
AMI	Automated metering infrastructure
BeOpt	Building Energy Optimization (an energy optimization software tool)
BPI	Building Performance Institute, Inc.
Btu	British thermal unit
CA HERS	California Home Energy Rating System
CARE	California Alternate Rates for Energy
CC	Community Center
ccf	100 cubic feet
CFL	Compact fluorescent lamp
CFM	Cubic feet per minute
CSI	California Solar Initiative
CT	Current transformer
CTCAC	California Tax Credit Allocation Committee
CUAC	California Utility Allowance Calculator
DAQ	Data acquisition
DR	Demand response
EE	Energy efficiency
EF	Energy factor (water heating)
EPRI	Electric Power Research Institute
ESA	Energy Savings Assistance
ET	Emerging Technology
EUC	Energy Upgrade California
HEMS	Home energy management system
HEPA	High-efficiency particulate air (air filtration system)
HVAC	Heating, ventilation, and air conditioning
kWh	Kilowatt-hour
LED	Light-emitting diode
LIMF	Low-income multifamily
LINC	LINC Housing, LLC
MASH	Multifamily Affordable Solar Housing program

Term	Definition
MEL	Miscellaneous electric load
MIDI	Middle income direct install
MMBtu	Million British thermal units
NILM	Non-intrusive load monitoring
Pa	Pascal
PACE	Property-Assessed Clean Energy
PHA	Public housing authority
PV	Photovoltaic (solar electric)
R-#	‘R-value’, measure of thermal resistance, higher number: lower heat flow
RTU	Rooftop (air conditioning and/or heating) unit
SCE	Southern California Edison
SCFH	Standard cubic feet per hour
SEER	Seasonal Energy Efficiency Ratio
SFS	Single feature substitutions
SOW	Statement of Work
SPF	Spray polyurethane foam
UA	Utility allowance
UV	Ultraviolet
VER	Very efficient retrofit
W	Watt
WCEC	Western Cooling Efficiency Center
ZNE	Zero net energy

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Appendix A: Example Scope of Work for Very Efficient Retrofit Measure

Scope of Work: Energy Efficiency Upgrades for the Common Area Community Center of the Beechwood Complex

Project and Technology Descriptions and Objectives

The scope of work described herein is an energy-efficiency retrofit of the common area in a multifamily building complex. This retrofit project is part of a research program to develop, install and evaluate packages of measures that can produce large, cost-effective efficiency gains in a low-income multifamily environment. This set of efficiency improvements, or "package" has been developed for installation, monitoring, and evaluation at the Village at Beechwood Community Center in Lancaster, CA. The package includes energy efficiency (EE) measures, solar thermal (hot water) and solar electric (PVs). A second component of this project is to identify, install, test/monitor, and evaluate new or under-utilized technologies or "emerging technologies (ETs). A contractor or set of contractors is required to purchase and install the ETs and this document provides this overview of the project and a brief description of each technology. The description section is followed by a detailed Scope of Work (SOW) for installation of each ET. That set of detailed SOWs should be the basis of the bid to do the prescribed installations. The emerging technologies, to be installed include a method to use an inert aerosol to seal the leakage areas of the building, making the building more air-tight, efficient and comfortable. The aerosol space sealing technology has been developed by the Western Cooling Efficiency Center at UC Davis, and they will "install" that ET. So there is no detailed SOW for that component of this bidding document. The other ETs include spray-foam roofing and duct insulation and sealant, economizer control, laundry-dryness dryer control, ozone generator and insertion into laundry washing machines to reduce or eliminate the need for detergents, "smart" electric extension-strips, catalyst demand-control ventilation systems and tankless water heaters.

The following is a brief description of each technology and the objective in installing and testing each technology. Following this descriptive section is the SOW for each individual technology:

Aerosol: The Aerosol space-sealing technology has shown to seal leaks in building envelopes, both in laboratory tests, and, recently, in actual homes in the field. This will be the first field test of sealing a multifamily dwelling. The primary of this project is to test the practical effectiveness of the aerosol-based envelope sealing methodology in a multifamily building application and estimate the first-cost savings and heating/cooling load reductions to accrue from this type of sealing. The building sealing technology is developed by researchers at the UC Davis Western Cooling Efficiency Center. Previous tests have shown a reduction of 50 percent in leakage areas. The researchers believe there is potential to further reduce building leakage area. The technology uses a compressed nitrogen nozzle to aerosolize the liquid sealant and disperse the aerosol sealant under pressure into the house. The sealant will follow small air-streams that form in and around the leaks; however, the mass of the aerosol causes the particles to hit the edges of the leaks, at which point some of the particles will stick to the edge. Over time, a deposit of the aerosol particles builds up in and around the leaks, sealing them.

This aerosol sealant installation will be provided by the Western Cooling Efficiency Center and is not part of the SOW to be bid by other Contractors. There is no corresponding reference to this ET in the next section. However, some coordination between this air sealing technique and other ETs installed in this project may be required.

1. Reroofing using polyurethane spray-foam with an elastomeric coating: The roof and HVAC ducts exposed above the roof of the community center will both benefit from any reductions in air leakage and improvements in insulation levels. Spray-applied polyurethane foam insulation (SPF) can provide both air sealing and a layer of insulation. The objectives of installing this SPF on the common area building at The Villages at Beechwood are to evaluate the cost and efficacy of SPF for both the air sealing of the ducts and the building, provide an insulating layer on both the roof and the ducts exposed above the roof, and this task will focus on the issues that are unique to multifamily applications, specifically how to deal with the possibility of sealant traveling from one apartment to another, or being wasted through large penetrations to piping chases. Two primary objectives in this research of employing aerosol technology: 1) test the practical effectiveness of the aerosol-based envelope sealing methodology in the common area of Beechwood Complex, and 2) estimate the first-cost savings and heating/cooling load reductions expected to accrue from this type of sealing.

   Spray Polyurethane foam (SPF) is formed when two liquid components are mixed at a 1:1 ratio inside a specialized spray gun, which generates tiny bubbles with isocyanates, polyols, catalysts and a non-ozone-depleting blowing agent when the mixture leaving the gun. The bubbles can expand 30 to 50 times larger than its original volume to insulate the roof. Spray polyurethane foam (SPF) is widely used for residential and commercial buildings with old and leaky flat or low-slope roofs. SPF offers high R-value that resists solar heat gains, long service life that should last the life of the house and only requires UV-resistant coating every 10 to 15 years. SPF is water resistant; water leakage only occurs if some foreign object penetrates the foam, producing a hole in the roof through which water can leak.

2. Dry Smart moisture sensor retrofit for laundry gas dryers: The objective is to use the moisture sensor to determine a load of clothes is dry and to stop the dryer cycle before additional energy is wasted. By reducing the drying time, the product is expected to save gas usage in the range of 15 percent to 30 percent, thus, improves the productivity of washers/dryers for the tenants.

3. Ozone enrichment to washers. Ozone generator takes in air and converts it into 90 percent oxygen, which is then electrically charged to form the ozone gas (O3). When operate a washer with ozone enrichment, the ozone gas is injected into the washer

wheel and it dissolves in the cold water, which opens up the fibers and releases stains. Opening up the fibers also makes the linens easier to dry and decreases drying time. After the washing cycle, the ozone is vented through a carbon tower and absorbed. Adding ozone equipment to washing machines is expected to greatly improve energy efficiency and laundry productivity and is also environmental friendly. 1) Hot water for laundry water supply is completely eliminated because ozone works best in cold water. 2) Reduction of washer and dryer cycle by a combined 30 percent so that the laundry can be used by tenants with higher productivity. 3) The vented ozone only leaves oxygen out of the exhaust thus it is not adding greenhouse gas emissions.

4. Catalyst demand control ventilation for rooftop air handlers. Catalyst is a packaged control system that converts constant air volume (CAV) system to variable air volume system that yields energy savings in the range of 25 percent to 50 percent. The objective is to upgrade the existing system with a packaged system that already includes several components and sensors developed as an easy-to-install kit that provides demand controlled ventilation and air-side economizing for energy and cost savings. The catalyst is controlled to provide maximum use of outside air for free cooling and assures proper ventilation based on the occupants in the room (by leveraging CO2 sensors in the package). The product provides a reduced fan energy reduction averaged at 69 percent and an improved air quality and quieter environment. The RTU's control and operation status are analyzed and translated into graphical information and reports for users to visualize through their phones or tablets that are connected to the internet.

5. Install Economizer retrofit kit on RTUs: An economizer can save substantial energy by introducing outside fresh air into the building when the outside temperature is at or below the inside set point. If no factory economizer retrofit kit can be found, the Roof Top Units (4 and 2 Ton), shall have custom economizers built and installed.

6. Smart power strips in the computer room. The common area is an ideal place to put on smart power strips to save standby power consumptions, because of the electric loads are constantly drawing current while idling, such as computer monitors, printers, TV and entertainment systems, etc. According to the U.S. Department of Energy, about 5 percent of the electricity used in the United States goes to standby power. Smart power strips as a surge protector that turns off the peripheral items when the computer is off or goes to sleep mode, and these peripheral items are turned back on only when the "master" device is turned back on.

7. Tankless water heaters. Tankless water heaters use high-powered gas burners to quickly heat up water temperature as it runs through the heat exchanger, which saves standby energy that would have lost in typical settings with water tanks for keeping the water warm, thus the heater is operated only when hot water is needed. Tankless water heaters can save up to 40 percent energy than traditional tank water heaters. The objective in this project is to investigate the efficiency of the tankless water heaters and investigate the energy and cost savings.

Task Descriptions

Task 3: DrySmart Moisture Sensor Retrofit for Laundry Gas Dryer

- Step 1: Record the operating time settings of each dryer in the laundry room. Monitor the gas usage of the common area, especially during weekends that most people use the dryers.
- Step 2: Install DrySmart moisture sensor retrofit and record the optimized operating time of dryers. This can be done by providing a survey in the laundry and by monitoring the gas usage of dryers during the weekend.
- Step 3: Compare results and an effective moisture sensor should reduce the operating time of dryers and thus reduce the gas usage. Because the clothes drying loads are not controllable before/after the retrofit, thus accurate reduction of gas usage is not easy to be obtained; however, the gas usage over long period of time (for example, a few months) should show slight decrease if the moisture sensor can work as expected to stop the dryers as soon as no more drying is needed.
- Step 4: Report on work implemented and results.

Task 4: Ozone Enrichment to Washers

- Step 1: Record the operating time settings of each washer in the laundry room. Monitor both electricity and water usage of the laundry room, especially during weekends that most people use the laundry room.
- Step 2: Install laundry ozone system to washers and also ozone monitor. The ozone monitor should be set to alarm at 0.05 parts per million. Some ventilation requirements should be followed with the specific requirements of the product.
- Step 3: An effective ozone enrichment upgrades should reduce both washing cycle and water usage. The upgrades will reset the washing cycle to a shorter time thus cost benefit of both electricity and water usage can be estimated as soon as the system is installed.
- Step 4. Monitoring the electricity use of the washers and a survey from tenants will help understand the electricity use of the washers and tenants' feelings of the product.
- Step 5: Report on work implemented and results.

Task 5: Smart Power Strips in the Computer Room

- Step 1: Identify the appliances in the common area should be controlled through the smart power strips (for example, computers, printers), how many strips will be needed and which device should be set as the "master" device. The peripheral items are shut off to cut standby power losses when the "master" device is turned off or goes to sleep mode.

- Step 2: Install the power strips with selected groups of devices. Monitor whether the power trips can turn off the peripheral items along with the “master” device.
- Step 3: Report on work implemented and results

Task 6: Tankless Water Heaters

- Step 1: Identify the equivalent BTU ratings of the tankless water heater that can replace the current three 100-gallon gas heaters.
- Step 2: Install the tankless water heaters and develop methods to investigate the efficiency improvement (for example, gas usage, run time, etc.)
- Step 3: Investigate the energy usage reduction
- Step 4: Report on work implemented and results

General Conditions

Permits and Approvals: The Sub-Contractor(s) shall secure all necessary permits pertaining to their own SOW, and ensure the work is inspected, and signed off by the local building and safety jurisdiction(s).

Commissioning (as appropriate): The Sub- Contractor(s) shall perform functionality checks on all equipment that the Subcontractors have installed on the project.

As-Builts: The General and the Sub-Contractors will provide the Project Team the As-Built drawings, construction notes and cut sheets for all equipment installed by the General Contractor and its Subcontractors. If no GC, The Sub-Contractors are obligated to provide As-Built drawings.

- Clean-up: Each Contractor will clean all areas (including all working areas and accessed area) daily to broom-clean standard or better when any work is performed. The Contractors shall not leave any tools, equipment, or parts in any home or stored on site, accessible to the public. LINC Housing, Beechwood, EPRI (and their subcontractors) and SCE are not responsible nor liable for any tools, equipment, or the like, misplaced or lost by contractors at the Beechwood site.

All Contractors hired for the project will meet the following specific Service Requirements:

Compliance with regulations, codes and licenses: All work shall be done in accordance with all applicable Federal, State, and local regulations, including California Code of Regulations, Title 24 Building Code, and CAL-OSHA, NEC, NFPA 70E. Only qualified Subcontractors (licensed by the State of California in their appropriate fields) will perform the work. Each crew shall have at least one Journeyman level tradesman on the crew, at the jobsite at all times.

- All work that requires a building permit shall be constructed in such a manner as to meet or exceed applicable building codes, and all such work will be approved (signed off) by the City of Lancaster Building Inspector.

Electrician

The electrical contractor shall determine the hazard/ risk categories as defined by NFPA 70E, and determine appropriate personal protective equipment to perform all electrical work and act accordingly.

Paint

All paint applied on the Beechwood project shall match the existing paint in sheen and quality with full coverage, one coat Primer, two coats paint, applied according to the Drywall Finishing Council's definition of Level 5 finish on a properly painted surface. These color and appearance requirements do not apply to the ducts or roof.

Plumbing (including solar domestic hot water)

All plumbing work shall be performed by Journeyman level workmen, using best industry-practices, meeting all applicable building and safety codes.

Plaster & Stucco

Will meet the requirements set forth in ASTM C 926, Standard Specification for Application of Portland Cement-Based Plaster and ASTM C 1063, Standard Specification for Installation of Lathing and Furring to Receive Interior and Exterior Portland Cement-Based Plaster.

Roof Integrity

The contractor will maintain the weather-tight integrity of the existing roofs on the homes and Community Center that the retrofit work is being performed on. Any roof penetrations will be guaranteed not to leak in accordance with the Warranty provisions of this Agreement.

Heat Pump (HVAC)

Heat pump shall be sized and installed to meet CA HERS Standards and Air Conditioning Contractors of America's Standard 9.

HVAC Duct and Envelop Air-Sealing

Both envelope and duct leakage tests shall be performed according to CA HERS or BPI procedures. Duct and envelope leakage tests shall be performed both prior to any retrofit work on the building, as well as after the retrofit work is finished. The post-retrofit test results should show that the duct leakage and building envelope are substantially more air-tight (lower leakage rates) than pre-retrofit (the baseline test leakages).

Detailed Scopes of Work

Re-Roofing – General preparation of roof area

The entire roof of the Community Center

1. Verify that all roof penetrations and flashings are properly installed and secured. If any flashings are rusted through at any point, they shall be replaced. Verify that metal roof

opening covers designated to receive polyurethane foam insulation are permanently secured.

2. Prepare surfaces using the specific methods recommended by the manufacturer for achieving the best result for the particular SPF substrate given the project conditions.
3. Provide masking protection as may be needed to prevent overspray of material on adjacent buildings and appurtenances, vehicles and portions of building not to be coated. Removal all overspray as required. Mask building surfaces to terminate the foam and coating in a neat, straight line.
4. Clean surfaces thoroughly prior to installation.
5. Apply primer to all surfaces to receive foam of type and rate as recommended by the foam manufacturer.
6. Verify that existing edge metal is properly attached and secured and that attachment is to a sound substrate. Any existing metal that is rusted through shall be replaced. Attachments must be in two rows staggered 3 inches (76 mm) on center.
7. Inspect all surfaces to receive spray foam insulation for structural soundness.
8. Remove and replace any wood nails, backing or other structural members that have lost their integrity.
9. Cut out and remove any wet substrate. Assure deck is properly cleaned, dried and primed prior to applying foam and coating.
10. Remove, raise or otherwise modify as necessary all existing roof-installed equipment to permit installation of roof system.
11. Mechanically attach all loose, slumping or otherwise deteriorated wall and penetration flashings with appropriate fasteners and plates.
12. Power broom, power wash and vacuum or otherwise remove all loose gravel, dirt, dust, oil, grease, etc. as may be necessary to create a strong bond between materials applied and existing roof.
13. Cover and protect all immovable objects and air intakes within area of spraying operations.
14. Verify that all roof drains and internal drain pipes are free of debris and draining properly prior to performing the re-roofing construction.
15. Drains should be at the correct elevation to match the specified height of the sprayed foam.
16. Mark all existing low areas where water ponds and areas with obviously poor drainage, to facilitate corrective procedures during roof system installation. Correct low areas by applying leveling foam of sufficient thickness in localized areas prior to applying the

minimum specified foam thickness. There shall be no water ponding on the completed roof deck.

Surface Preparation - Metal HVAC Ducts

1. Clean exposed metal duct surfaces to be free of all rust, scale, dirt, grease, oil, chalking, paint or other contaminants.
2. Galvanized Steel shall be primed using an acid wash primer.
3. Prime all metal with Bayblock Prime RI at the rate of 300 square feet per gallon.

Surface Preparation - Existing Built-up Roof

1. Power broom, power wash and vacuum or otherwise remove all loose gravel, dirt, dust, oil, grease, etc. as may be necessary to create a strong bond between materials applied and existing roof.
2. Exercise care in removing of gravel so as not to damage top layer of roofing felts. Do not allow large amounts of gravel to accumulate in any one location that might overload the roof deck structure.
3. Cut out all existing blisters, fish mouths, buckles, ridges, felt delamination, punctures and soft spots in an industry acceptable manner.
4. Repair membrane splits by removing the gravel and cleaning an area six inches wide on each side of split. Mechanically attach the membrane on each side of the split.
5. Inspect substrate thoroughly for moisture. If evidence of moisture is suspected, then special moisture detection method must be used to determine the exact locations of wet substrate. Wet substrate, if encountered, and other unsuitable materials shall be cut out, deck properly cleaned, dried and primed prior to applying foam and coating.
6. Mechanically attach all loose, slumping or otherwise deteriorated wall and penetration flashings in accordance with manufacturer’s recommendations.
7. Prime all existing asphaltic substrates with Bayblock 100 at the rate of one gallon per 100 square feet.

Spray Polyurethane Foam Application

1. Apply polyurethane foam in strict accordance with the manufacturer's specifications and application instructions.
2. Apply in a minimum of 1⁄2 inch (12.5 mm) thick passes and 1-1/2 inch (38 mm) maximum thick passes. Total thickness of the polyurethane foam shall be a minimum of 1 inch (25.4 mm), except where tapering is required to facilitate drainage.
3. Apply the full thickness of polyurethane foam in any area on the same day (3”, R-17).

4. Applied to ensure proper drainage, resulting in no ponding water. Ponding water is generally defined as "an area of 100 square feet or more, which holds in excess of 1⁄2 inch (12.5 mm) of water as measured 24 hours after rainfall.
5. Terminate polyurethane foam neatly a minimum of 4 inches (102 mm) above the finished roof surface at roof penetrations. Foamed-in-place cants shall be applied to allow a smooth transition from the horizontal to vertical surface and shall be applied prior to the application of additional foam lifts to achieve specified thickness. Mask building surfaces to terminate the foam and coating in a neat, straight line.
6. Finished polyurethane foam surface texture shall be "smooth to orange-peel", free of voids, pinholes and depressions. "Verge of popcorn" texture is acceptable if it can be thoroughly and completely coated. Popcorn and tree bark textures are not acceptable. Unacceptable foam textures must be removed and re-foamed prior to coating application.

Application of Acrylic Elastomer Roof Coating

1. Polyurethane foam surface shall be free of moisture, dust, dirt, debris and other contaminants that would impair the adhesion of the silicone coating.
2. If foam is exposed in excess of three days and additional foam thickness is necessary, or surface oxidation has occurred surface shall be primed before coats. Prime with Bayblock Prime NS primer applied at a rate of 200 square feet per gallon.
3. Spray and apply coating in accordance with the manufacturer's application instructions and precautions in the technical datasheet.
4. Apply acrylic elastomeric roof coating on the same day as the polyurethane foam application, and after the polyurethane foam has been allowed to cure a minimum of one hour. If the basecoat is not applied within 24 hours of polyurethane foam, remove and repair all signs of oxidation, or other damages as required by manufacturer.
5. If foam is exposed in excess of three days and additional foam thickness is necessary, or surface oxidation has occurred surface shall be primed before coating with acrylic elastomeric roof coating. Prime with Bayblock Prime NS applied at a rate of 200 square feet per gallon.
6. Acrylic elastomeric coatings coating shall be applied in a minimum of three separate coats by spray or roller at the rate of 1-1/4 gallons per coat per 100 square feet.
7. Allow each coat to cure a minimum of 12 hours before proceeding with successive coats. Second and successive coats must be applied within 48 hours to ensure good adhesion. Allow top coat to cure a minimum of 72 hours without foot traffic.
8. Nominal thickness of the final dry film protective elastomeric acrylic coating system shall be an average 33 mils with a minimum of 28 mils.

9. Edges of the roof shall be pre-coated in a "picture framing" fashion so as to have at least one additional coat on the edges than the field of the roof.
10. Mask off metal and other surfaces not to receive coating.
11. All foam is to be coated. Coating shall be extended up and over all foam or vent pipes and terminate a minimum of 2 inches (51 mm) above the foam creating a self-terminating flashing.
12. Coat foam the same day of application, unless delayed by inclement climatic conditions.
13. Equipment Walkway Coatings: Roofing granules or a reinforced polyester mesh shall be installed around all mechanical equipment as indicated on the Drawings. Install at least six feet around the perimeter as follows:
    - Apply an additional coat of acrylic coating at the rate of 1-1/2 gallons per 100 square feet.
    - Broadcast grade 11 roofing granules at a rate of 50 pounds per 100 square feet or lay down the reinforced polyester mesh while the coating is in a fluid condition.
    - Seal granules or polyester mesh in by applying additional coating at the rate of 3/4 gallon per 100 square feet.

Field Quality Control

1. Roof system manufacturer shall provide independent inspection firm, to perform periodic follow-up inspections on the roof, through a standard warranty inspection program at no expense to the contractor.
2. Any areas that do not meet the minimum standards for application as specified herein shall be corrected by the applicator. Manufacturer's inspection or verification shall not constitute acceptance of responsibility for any improper application of material.
3. Protect installed products until completion of project.
4. Touch-up, repair or replace damaged products before Substantial Completion.

Materials Definitions and standards

The following materials are available through Bayer. Other manufacture’s products are acceptable, provided they meet or exceed the full list of properties of these Bayer materials. The full specifications of these listed materials area available from Bayer and are provided in the full document from which these sections were extracted.

<u>Bayblock</u> - A single component, water-based, general purpose primer to for the preparation of most non-metallic surfaces for the application of elastomeric coatings and spray polyurethane foam. Suitable for built-up roofing, wood, concrete, spray polyurethane foam, aged asphaltic and other substrates.

Base Coat: Acrylic elastomeric coatings (for example, Bayblock II Base) a technologically advanced, high-solids, fire retardant, thixotropic, acrylic latex coatings uniquely formulated for the protection of sprayed-in place polyurethane foam insulation, stucco, concrete block, metal, single ply, and modified bituminous roofing.

Top Coat: for example, Bayblock HT a technologically advanced, high-solid, alkali resistant, thixotropic, acrylic elastomeric coating uniquely formulated for the protection of sprayed-in place polyurethane foam, metal, polyurea, stucco, siding, and concrete.

Foam insulation Scope of Work

Scope of Work for re-roofing using polyurethane spray-foam with an elastomeric coating.

These installations procedures and protocols sections were extracted from a complete, but generic re-roofing protocol (#075760 from Bayer Material Science). Sections deemed pertinent were extracted, sometimes slightly altered, and compiled here to comprise the Scope of Work for retrofit-roofing of the building, and insulating and sealing the HVAC ducts on the roof of the Community Center building within the Village at Beechwood.

PROJECT CONDITIONS

A. Maintain environmental conditions (temperature, humidity, and ventilation) within limits recommended by manufacturer for optimum results. Do not install products under environmental conditions outside manufacturer's absolute limits.

B. Do not apply polyurethane foam or roof coating during periods of rain, snow, fog, and mist.

C. Do not apply the polyurethane foam when substrate or ambient air temperatures are below 50 degrees F (10 degrees C) or above 120 degrees F (49 degrees C), or when wind velocities exceed 15 mph. Do not apply polyurethane foam when the substrate surface temperature is less than 5 degrees F (minus 15 degrees C) above the ambient temperature.

D. Do not apply acrylic roof coatings at temperatures below 50 degrees F (10 degrees C) or when there is a possibility of temperatures falling below 32 degrees F (0 degrees C) within a 24-hour period.

E. Use windscreens during the application of the polyurethane foam and roof coating to prevent overspray onto surfaces not intended to receive foam and coating. Under no circumstances shall the polyurethane foam be applied when wind speeds exceed 15 miles per hour.

DELIVERY, STORAGE, AND HANDLING

A. Store products in manufacturer's unopened packaging, clearly marked with the manufacturer's name, brand name, product identification, type of material, safety information, manufacture date, and lot numbers until ready for installation.

B. Store acrylic coating materials between 50 degrees F (18 degrees C) and 90 degrees F (29 degrees C) with careful handling to prevent damage to products. If conditions exceed these ranges, special consideration in storage must be taken. Do not store at high temperatures in direct sunlight.

C. Protect all materials from exposure to moisture, freezing and other damage during transit, handling, storage, and installation.

D. Store and dispose of solvent-based materials, and materials used with solvent-based materials, in accordance with requirements of local authorities having jurisdiction.

SAFETY REQUIREMENTS

A. Exercise care not to allow fumes from the polyurethane foam and coating materials to enter the building, using the following minimum precautions:

B. Turn off all HVAC equipment and cover all intake vents and other potential sources of air entry into the building.

C. Provide CO2 or other dry chemical fire extinguishers to be available at the jobsite.

D. Provide adequate ventilation for all areas being worked.

E. Proper safety precautions shall be followed throughout the entire roofing operation. Conform to safety precautions of Spray Polyurethane Foam Alliance of the American Plastics Council’s Recommendations for the Safe Handling and Use of Sprayed Urethane Foam and Coating Materials.

F. Provide fire extinguishers available on the roof and at all work sites at all times during roofing operations.

SOW 2: Installation Instructions for Moisture Sensing kit for dryer

- Specifications of kit – sufficient to purchase correct item
- Place Detailed installation instructions here

SOW 3: Installation instructions for ozone washing system

- ULTRAVIOLET (UV) OZONE SYSTEMS Ozone is manufactured in the UV ozone generator by drawing in air, which is composed of 20 percent oxygen (O2), and exposing it to the radiation of a specific wavelength from a specially designed ultraviolet lamp. This causes a percentage of the oxygen molecules to dissociate and reassemble as ozone (O3). The ozone is drawn into the water by an injector/mixer, killing any bacteria, viruses or mold spores it contacts. Ozone is generated on-site, eliminating the need to store toxic and corrosive chemicals. The corona discharge method is the most efficient way to produce large amounts of ozone. 3 - O2 2 - O3 Chemical Formula (simplified) for Corona Discharge Ozone ClearWater Tech ozone systems are capable of oxidizing iron, sulfide, manganese and act as an efficient sanitizer in a variety of applications. Ozone reacts to water-borne contaminants much faster than other disinfectants and the primary by-product is pure oxygen. ClearWater Tech ozone systems are built with the finest components available. They are most efficient when used with a venturi injection system to create the best possible contact and mixing of ozone while maintaining a high level of safety.

- UNPACKING and INSPECTION Shipping Terms: Unless special arrangements have been made, the ozone equipment will be shipped FOB ClearWater Tech's factory in San Luis Obispo, CA. The freight charges will be prepaid and billed or shipped freight collect. Transfer of liability to the freight company and the customer occurs as the equipment leaves the factory loading dock and is accepted by the freight line. Freight Inspection All equipment should be thoroughly inspected immediately upon delivery. If any damage is noticed, promptly notify the freight line and request an on-site inspection. Unpacking Compare the components with the packing list. Thoroughly inspect all packing materials prior to discarding. Inspect all plumbing fittings and tubing for packing material inadvertently lodged in any openings. MOUNTING Pick a location as close to the injector as possible to mount the ozone generator. While the ozone generator enclosures are rain tight, it is best to pick a location out of the sun and rain. On the back / top side of the enclosure are mounting holes; the unit can be attached to a wall using these mounting holes. INSTALLATION CLEARWATER TECH MODEL MZ-250 CLEARWATER TECH MODEL S-1200 CLEARWATER TECH MODEL CS-1400 CLEARWATER TECH MODEL UV-2800 CLEARWATER TECH MODEL UV-2800 Internal Components USING AN SCFH GAUGE (Must be ordered separately) An SCFH (Standard Cubic Feet per Hour) gauge is used to accurately measure the amount of air flowing through the ozone delivery line. This affects the amount of ozone being injected into the water. 1. Install the tube fitting into the upper hole on the back side of the SCFH gauge. 2. With the pump running, disconnect the tubing from the ozone outlet of the ozone generator and connect the tubing to the fitting on the gauge. 3. While holding the gauge vertically, read the amount indicated on the gauge. The optimum flow is 10 to 20 SCFH. NOTE: Do not obstruct the bottom air hole on the gauge. 4. ClearWater Tech injector manifolds have a ball valve to adjust the amount of flow. To adjust the SCFH, simply install the gauge as described above and open the ball valve completely. With the pump running, begin closing the ball valve until optimum flow is achieved on the SCFH gauge. If possible, remove the ball valve handle to prevent tampering. ELECTRICAL WIRING The object is to have the ozone generator come on whenever the pump comes on for filtration or circulation. The installation should be done by a licensed electrician. All local codes must be observed. There are several ways to wire the ozone generator: 1. To a timer. 2. To a service disconnect 3. Directly to the electrical panel. The ozone generator is available in 120 volts and 240 volts. Be sure to install the proper system for your application. Before attempting any electrical hookup, be sure the power is OFF at the main circuit box. To hard wire a 120V system: Run the black (hot) wire to the ‘hot’ terminal on the timer, service disconnect or electrical panel. Run the white (neutral) wire to a neutral terminal or buss bar. Then run the ground wire to a ground terminal or buss bar. To hard wire a 240V system: Run the black wire to one of the ‘hot’ terminals on the timer, service disconnect or electrical panel and run the red wire to the other ‘hot’ terminal. Run the green wire to ground. BONDING REQUIREMENTS: You must install a ground lead from the bonding lug (on the bottom left of the unit) to a natural earth ground. This bonding wire should conform to all local, state and national electrical codes. (The standard recommendation is a #8 AWG copper wire.) Injector Manifold with Check Valve Do not block lower hole. Attach ozone line KEEP GAUGE VERTICAL TYPICAL INSTALLATION FOR ATMOSPHERIC TANK RECIRCULATION SYSTEM 1. When ClearWater Tech ozone generator units are to be used for atmospheric tank recirculation, observe all general installation steps and electrical connection instructions. 2. On an ozonated recirculation system, all pumps and venturis should be protected by valves and unions to facilitate servicing. In general, low pressure check valves may be used on the venturi. 3. A typical recirculation system should inlet from the bottom of the tank and return to the bottom of tank, forcing the water in a circular pattern (even if the piping must extend over from the top of the tank to the bottom). 4. If an ORP monitor is to be used for ozone residual indication or control, the sensor should be mounted between the tank isolation valve and the pump inlet. This is also a good location for a flow meter. (Observe the manufacturers recommendations for flow meter installation.) 5. Depending on water quality and ozone generator size, a 24 hour timer or delay timer is a useful accessory. For additional information on tank turnover times, alternative techniques or accessories, consult your ClearWater Tech representative. Style A Circulator Reverse Osmosis and Water Storage Tanks up to 1500 Gallons Style B Circulator Treatment and Storage Tanks up to 20,000 Gallons Isolation Valve Ozone from ozone generator Isolation Valve ClearWater Tech PRO 10/12/14 Isolation Valve From Ozone Generator Venturi Injector Low Pressure Check Valve Circulation Pump Unions Isolation Valve ORP Probe OR INSTALLATION WITH THE CLEARWATER TECH OAS-20 UNIT: Typical pressurized installation for water treatment or odor control system 1. Mount the OAS-20 and the ozone generator adjacent to each other on a sheltered surface. 2. Remove the cover mounting screws on the ozone generator and locate the barbed air inlet fitting at the bottom of the UV lamp chambers. (See the unit illustrations earlier in this manual.) 3. Cut a length of 1/4" braided tubing provided and attach between the air outlet fitting on the OAS-20 and the barbed inlet air fitting on the ozone generator. 4. Connect the remaining 1/4" braided tubing to the barbed fitting on the ozone outlet of the ozone generator (the check valve on the UV-2800). 5. Connect the opposite end of this tubing to the ozone dispersion ring and place in the bottom of the tank, running the tubing above the water level of the tank. 6. Plug the ozone generator power cord into the switched outlet on the OAS-20. 7. To initiate operation, set the timer by rotating the blue timer dial clockwise to indicate the current time of day. Pull outward on the blue tabs to indicate the current time of day. Pull outward on the blue tabs to engage the air source at the indicated time for 30 minutes per tab. NOTE: Extreme caution should be exercised if this unit is to be used for open atmospheric odor control. The use of an ambient air monitor is strongly recommended for safety. Air Outlet 120 VAC 120 VAC Air ClearWater Tech Air Source/Timer Ozone Ozone Dispersion Ring

SOW 5: Smart power strips in the computer room and Beechwood offices

Smart power strips (AKA “plug load timers”), will be installed to automatically turn equipment off when the equipment is not in use. The smart power strips will turn off equipment that has gone into low power mode while not in use. Note: The user will need to turn on the plug load timer switch to use any equipment connected to these strips.

SOW 6: Install Economizer retrofit kit on RTUs

An economizer can save substantial energy by introducing outside fresh air into the building when the outside temperature is at or below the inside setpoint. If no factory economizer retrofit kit can be found, the Roof Top Units (4 and 2 Ton), shall have custom economizers built and installed.